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Abstract booklet

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Index

Abstracts

Below appear the abstracts for all accepted submissions to the Meeting. This section is automatically generated from the submission website and may not reflect recent updates, such as withdrawn contributions or changes in authorship.

First appear the keynote addresses, then the symposium presentations, then the regular submitted presentations, and finally the posters.

Keynote Addresses

Digging Deeper into the Temporal Structure of the Mind

Anderson, John R.

Neural imaging can be used to identify the stages of mental processes. We have used a combination of hidden semi-Markov models and multivariate pattern matching (HSMM-MVPA) to analyze MEG data from memory experiments. The HSMM-MVPA methods are able to reveal brief bumps in the sensor data that mark the onset of different stages of processing. We used these bumps to isolate encoding, retrieval, decision, and response stages within single memory trials. The temporal distributions of these stages as well as the brain regions engaged indicate that the same stages occur in two rather different experiments (associative recognition of word pairs versus recall of arithmetic facts). This new technique allows the retrieval stage to be isolated from the rest of a trial. This in turn allows us to test theoretical claims concerning the distribution of retrieval times and how they vary with condition.

Informing Cognitive Abstractions with Neurophysiology

Turner, Brandon (William K. Estes Early Career Award Recipient)

Our understanding of cognition has been advanced by two traditionally non-overlapping and non-interacting groups. Mathematical psychologists rely on behavioral data to evaluate formal models of cognition, whereas cognitive neuroscientists rely on statistical models to understand patterns of neural activity, often without any attempt to make a connection to the mechanism supporting the computation. Both approaches suffer from critical limitations as a direct result of their focus on data at one level of analysis (cf. Marr, 1982), and these limitations have inspired researchers to attempt to combine both neural and behavioral measures in a cross-level integrative fashion. The importance of solving this problem has spawned several entirely new theoretical and statistical frameworks developed by both mathematical psychologists and cognitive neuroscientists. In this talk, I will discuss a recent approach called joint modeling that mutually constrains what we learn about the cognitive process from both the computational model and the neurophysiology. The central idea of this approach is to use the information in the neurophysiology to enhance or guide what the cognitive model says about the cognitive process of interest. I will highlight the utility of this approach in a variety of applications.

A Less Simple, but More Complete Model of Choice Response Times: Stochastic Linear Ballistic Accumulation

Donkin, Chris (William K. Estes Early Career Award Recipient)

Brown & Heathcote's (2008) Linear Ballistic Accumulator (LBA) Model provides an impressive account of observed human response time distributions, including complex patterns of correct and incorrect response times. One shortcoming of the LBA model is that it makes the unrealistic assumption that the rate of evidence accumulation is determininstic. Holmes, Trueblood and Heathcote (2016), with their piece-wise LBA model, assumed that the rate of evidence may change once during the decision process, thus making the model more realistic. Here, I present a natural extension of the piecewise LBA model, the stochastic Linear Ballstic Accumulator (sLBA) model. The sLBA model assumes that the change in evidence accumulation rate occurs approximately infinitely many times during a decision, while maintaining a constant overall rate of drift. The sLBA accounts for all of the benchmark data as well as the LBA model, but explicitly models the noisy evidence accumulation process that is carried out by the brain.

Symposium Presentations

Symposium: *Integrating Prior Knowledge with Memory*

Toward Ecologically Realistic Theories in Visual Working Memory Research

Jacobs, Robert

Visual working memory (VWM) helps people perceive, reason, and act in normal, everyday environments. Consequently, it exploits the regularities of natural environments to enhance its performances. Research on VWM, however, often uses experimental stimuli and procedures that are inconsistent with the regularities of natural environments. We argue that this research provides a potentially distorted view of VWM. In this talk, we will discuss two research projects from our lab. The first project studies the hypothesis that VWM exploits the fact that natural environments tend to be "clumpy", meaning that items in these environments often belong to a small number of clusters or categories. The "clumpiness" assumption can make VWM more efficient, though it can also lead to biases and dependencies in people's memories. The second project focuses on the relationship between visual perception and visual working memory. We advocate for the development of unified models of visual perception and VWM --- probabilistic and hierarchical in nature --- incorporating prior knowledge of natural scene statistics. These projects were conducted in collaboration with A. Emin Orhan (Center for Neural Science, New York University).

Memory and Structure

Gershman, Sam

When do we modify old memories, and when do we form new memories? I present theoretical arguments and experimental data, ranging from classical conditioning to visual cognition, that the tension between memory modification and formation is resolved through a process of probabilistic inference. In particular, I argue that new memories will be formed when new latent causes are inferred. According to this view, memories store the sufficient statistics of distributions over perceptual data, where each distribution is indexed by a latent cause. Memory formation is thus a structure learning problem: memories reflect how our brains "carve nature at its joints."

A More Rational Theory of Perceptual Memory

Sims, Chris

Perceptual memory is a system that exists to aid in the achievement of behavioral objectives (such as object comparison, correspondence, motor control, navigation, etc.). This requires extracting and storing useful information from noisy and uncertain sensory signals. At the same time, given the complexity of sensory information and the limitations of biological information processing, it is clear that some information must be lost or discarded in the act of encoding perceptual memories. Under these circumstances, what constitutes an optimal perceptual memory system? This talk will introduce rate-distortion theory (originally developed by Shannon) as the normative framework for understanding perceptual memory as a rational, but limited system. Rate–distortion theory offers a general and principled theoretical framework for developing computational-level models (Marr, 1982) of human perception. This approach clarifies that perceptual memory is a physical information channel that, by necessity, possesses a finite limit on information transmission. Consequently, optimal perceptual memory is defined by minimizing the task-defined cost of perceptual error with respect to both the memory encoding and decoding process, subject to a constraint on channel capacity. Much like Bayesian theories of perception and memory, this requires exploiting prior knowledge of relevant statistics. In addition, an optimal perceptual memory system must be defined with respect to a particular and explicit cost function: a mathematical construct that defines the cost of different types of memory error. This provides a natural and an explicit grounding of perceptual memory in terms of important natural tasks. Importantly, unlike Bayesian models of perceptual memory, rate–distortion theory avoids atheoretical assumptions regarding the encoding process (such as the nature or magnitude of memory noise). Experimental data will be presented from several domains including color perception and memory, haptic memory, and the effects of expertise on perceptual memory.

How Visual Working Memory Exploits Environmental Structure

Vul, Ed

How do people use the structure of items when storing them in visual memory? An iterated learning experiment reveals that people expect visual scenes to be hierarchically organized into self-similar groups, and that this expectation biases visual memory. A series of subsequent experiments on the error structure of recall reveals that the inferred hierarchical structure not only biases what people

remember, but also influences how people forget: memory errors can be attributed to different nodes in the hierarchical parse by virtue of the relationships between errors for different objects. Together, these results show not how people use environmental structure to remember displays, but also that the inferred scene hierarchy influences the encoded data structure in memory.

Semantic Influences on Episodic Memory Retrieval

Kahana, Michael, Long, Nicole, Healey, M. Karl, and Manning, Jeremy

Recent corpus-based tools have made it possible to characterize the similarity structure of all of the words in an entire language. This has provided researchers with an unprecedented ability to characterize the role of prior linguistic knowledge on the formation and retrieval of new episodic memories. In this talk, I will summarize empirical findings concerning the complimentary roles of semantic and temporal similarity on the dynamics of memory search, and the challenge these findings pose to computational models of human memory. I will also present new findings concerning the electrophysiological biomarkers of temporal and semantic factors in episodic memory encoding and retrieval.

Does Prior Knowledge Influence the Fragility of Associations in Memory?

Hemmer, Pernille, and Persaud, Kimele

A fundamental question of memory is what happens to the information stored in memory traces over time. Research suggests that once the working memory capacity is reached, the fidelity of the trace is fixed (Zhang & Luck, 2008). Furthermore, fidelity is assumed to remain stable even into long-term memory (Brady, Konkle, Gill, Oliva, & Alvarez, 2013). While overall long-term memory has an impressive storage capacity, the system struggles to form and store associative information between memories, resulting in fragile associations (Lew, Pashler, & Vul, 2015). This difficulty in storing associative information may result from the unnatural state of the associations. The unnaturalness may also hamper the employment of prior knowledge, which has been demonstrated to improve performance in long-term memory (Hemmer & Steyvers, 2009; Persaud & Hemmer, 2014). In this way prior knowledge learned from the regularities of the natural environment play an important role in long-term memory. Here we present work where we manipulate the meaningfulness of associations, relative to the natural environmental structure, to determine the role that prior knowledge plays in the forming and storing of associations in long-term memory. Models of long-term memory that account for natural and unnatural to-be-recalled information are discussed.

The Primary and Convergent Retrieval Model of Recall

Hopper, William J., and Huber, David E.

We present a new memory model, termed 'The Primary and Convergent Retrieval Model' (PCR), which explains the benefits of retrieval practice as a study technique (aka, the 'testing effect'). Like previous models, PCR assumes that new associations between a target item and retrieval cues produce an initial retrieval state. We term this 'Primary Retrieval'. Most memory models include a second process for recall, variously termed 'recovery' or 'pattern completion'. However, these models do not specify the time necessary for this second process and the kinds of learning that uniquely affect this second process. We term this gradual pattern completion process 'convergent retrieval' and we assume that this is the main source of variation in recall latencies. In PCR, learning depends on the timing of feature activations, predicting that successful recall, but not study, creates new associations between the features of a retrieved target item. This selectively benefits the convergent retrieval process. Test practice is typically worse than study practice with an immediate final test, but better than study practice after a delay. PCR explains this crossover interaction and, furthermore, predicts that recall latencies will be faster following test practice regardless of delay. We confirmed this prediction both with free recall and cued recall. Furthermore, we found faster cued recall latencies following test practice even when the final test used a different retrieval cue than test practice. PCR explained accuracy and recall latency distributions as a function of: 1) output position in free recall; and 2) combinations of test practice and final test accuracy in cued recall.

Symposium: *Probabilistic Approaches to Perceptual Organization*

Probabilistic Approaches to Perceptual Organization

Feldman, Jacob, and Singh, Manish

Perceptual organization---the process by which the visual field is grouped into coherent units and objects---is a central problem of perception, but has proven very difficult to formalize. Recently however research on these problems seems poised for the development of a set of new mathematical paradigms, including Bayesian frameworks as well as other probabilistically-motivated approaches. This Symposium brings together researchers in this area to share ideas about probabilistic approaches to perceptual organization, and also to think collectively about some of the obstacles they may face.

Model-Based Perceptual Grouping and Shape Abstraction

Dickinson, Sven

For many object classes, shape is the most generic feature for object categorization. However, when a strong shape prior, i.e., a target object, is not available, domain independent, mid-level shape priors must play a critical role in not only grouping causally related features, but regularizing or abstracting them to yield higher-order shape features that support object categorization. In this talk, I will present a framework in which mid-level shape priors take the form of a vocabulary of simple, user-defined 2-D part models. From the vocabulary, we learn to not only group oversegmented regions into parts, but to

abstract the shapes of the region groups, yielding a set of abstract part hypotheses. However, the process of shape abstraction can be thought of as a form of "controlled hallucination", which comes at the cost of many competing 2-D part hypotheses. To improve part hypothesis precision, we assume that the 2-D parts represent the component faces of aspects that model a vocabulary of 3-D part models. We then exploit the relational structure (spatial context) of the faces encoded in the aspects, and formulate hypothesis selection in a graph-theoretic, probabilistic framework. Finally, we introduce a technique that is able to recover the pose and shape of a volumetric part from a recovered aspect, yielding a framework that revisits the classical problem of recovering a set of qualitative 3-D volumetric parts from a single 2-D image.

Simplicity vs. Likelihood in Perceptual Organization and in Statistical Inference: a “Best Buy” Model of Perception

Kubovy, Michael

Since Pomerantz & Kubovy’s (1988) Theoretical approaches to perceptual organization, many attempts have been made to understand the value of the simplicity and the likelihood principles. I will first briefly review of the history of the question. The main purpose of my talk is to ask whether it is fruitful to consider the visual system as a statistical unconscious inference device. The function of such a device would not be to construct a true model of the world (since such a model is unattainable), but to construct the most useful model of the world. A model can be evaluated in two ways: its bias^2 and its variance. A system that allocates all the resources available to it (e.g., degrees of freedom, computational complexity) to constructing the model will be unbiased w.r.t. the current data it has, but as soon as an organism’s ecology changes ever so slightly it will be highly biased, resulting in a high variance in the parameters of the model as the organism moves in its world. Akaike’s strategy of using an information criterion (IC) to gauge the proper balance between bias^2 and variance, may also help us better understand the simplicity vs. likelihood debate. If we think of degrees of freedom as a currency that can buy model quality, the IC provides a way of assessing whether a model is worth the cost, i.e., whether it should be recommended to the perceptual system as a best buy. This approach may help us understand why different organisms construct models of their ecology that differ enormously in their complexity.

Visual Perceptual Organization Generalized

Gepshtein, Sergei

Studies of visual perceptual organization concentrate on a narrow class of stimuli: fragmented high-contrast patterns displayed on flat surfaces and viewed by static observers in small spaces. I will review two related approaches toward breaking the narrow focus. The first approach is the study of neural mechanisms engaged by optical patterns within and without those favored by researchers of perceptual organization. Perception of both continuous and fragmented stimuli, near the threshold and above it, is predicted by a model of mechanisms tuned to multiple spatiotemporal scales of stimulation. Biologically plausible implementations of such multiscale models are intrinsically stochastic, helping to reduce the challenge faced by probabilistic models of perceptual organization to the broader question of how neural systems handle uncertainty. The second approach is the study of how visual environments are

experienced by mobile observers. From the perspective of the first approach, perceived environments should have the familiar part-whole structure, as do the objects studied under the rubric of perceptual organization. On this view, every environment is divided to solid regions that afford experience of different parts of the environment. The solid regions may overlap or nest in one another. I will describe a model of perceptual organization of space derived from this premise and tested using large-scale robotics. In summary, the same stochastic multiscale model predicts the perceptual organization of visual environments and the objects that populate such environments.

Solving 3D Symmetry Correspondence Problem from a Single 2D Image

Pizlo, Zygmunt, Jayadevan, Vijai, and Michaux, Aaron

3D shape recovery from a single 2D retinal or camera image is an ill-posed inverse problem, whose solution critically depends on the use of priors. Our previous work showed that the 3D symmetry prior plays a critical role in human 3D shape perception. Before this prior is applied, the visual system has to solve the symmetry correspondence problem. This problem is analogous to other correspondence problems in vision, but is more difficult because the correspondences in the 2D image represent pairs of different (symmetrical) 3D features which are usually spatially distant. We present a computational model that provides a partial solution to the symmetry correspondence problem. We assume that the vanishing point representing 3D mirror symmetry is known. We then extract curves representing meaningful contours using a shortest path algorithm, in which the cost depends on the size of interpolations and the magnitude of turning angles. These curves are then used to solve an optimization problem in which 2D curve similarity and 3D piece-wise planarity are used as priors. Our method will be illustrated using real images of furniture pieces.

Probabilistic Approaches to Hierarchical Clustering

Heller, Katherine

I will discuss our Bayesian Hierarchical Clustering algorithm, which successfully takes a Bayesian approach to traditional hierarchical clustering, making merges based on marginal likelihoods, instead of distance metrics, but with a similar computational complexity. The advantages of using probabilistic methods for clustering data as opposed to traditional distance metric based algorithms will be shown. I will also present our recent work on predictive hierarchical clustering, which is being used better cluster surgical procedural codes, and thus obtain better results in predicting surgical complications for patients.

Symposium: *Trends in Modeling Cognition with Cognitive Architectures*

What is Distraction? Modeling the Elusive Process of Mind-Wandering

van Vugt, Marieke

A process that is very difficult to model is that of mind-wandering, because it is not directly driven by a specific task, and because people may have different ways of engaging in mind-wandering. Cognitive architectures can make these strategies explicit and thereby help us understand when, how, and why people mind-wander. Distraction is commonplace in modern-day society, and neuroscientific research into mind-wandering is expanding. Here we propose a process model of mind-wandering, and show that this computational model can describe both objective behavioral and subjective introspective data from two different mind-wandering experiments. Our model is based on the idea that there is a continuous competition between a task goal and a distraction ``goal''. As the task goal decays over time, the distraction goal can take over, and when that happens, a mind-wandering process is put into action. The characteristics of this mind-wandering process determine what the effects are on performance of the main task. Our model can accurately predict performance on tasks routinely used to study mind-wandering—sustained attention tasks in which participants are periodically probed about whether they are on- or off-task. Our model is able to respond to these queries about its introspective experience. The model can subsequently be used to develop an explanation for how mind-wandering differs from less innocent distractions such as rumination.

Using Data-Driven Model-Brain Mappings to Constrain Formal Models of Cognition

Borst, Jelmer

Cognitive models are notoriously hard to evaluate, especially based on behavioral measures alone. Neuroimaging data can provide additional constraints, but this requires a mapping from model components to brain regions. Although such mappings can be based on the experience of the modeler or on a reading of the literature, a formal method is preferred to prevent researcher-based biases. In this talk I will first explain how we used model-based fMRI analysis to create a model-brain mapping for the ACT-R cognitive architecture. This mapping is based on five previously published fMRI datasets and associated models, ranging from associative recognition to multitasking. I then demonstrate how this mapping can be used to evaluate new models. In my first example, the model was supported by the fMRI data, while the second model needed to be adapted, even though it matched the behavioral data well. I conclude that data-driven model-brain mappings can provide strong constraints on cognitive models, and that model-based fMRI is a suitable way to create such mappings.

Functional Analysis of Movement Behavior for Human-Computer Interaction

Blaha, Leslie M.

Developing effective interfaces for human-computer interaction requires not only an understanding of the relevant perceptual and decision processes but also an understanding of how input modalities and the structure of the user interactions both reflect and shape cognitive behaviors. This creates a prime opportunity for bridging mathematical and computational modeling approaches to understand input behavior, particularly mouse, touch screen, and eye movement trajectories. Mathematical models offer thorough characterizations of measured movement behaviors. Computational models offer simulation capabilities that can support model-based evaluation of candidate interface designs. We demonstrate this synergy by leveraging a combination of Gaussian Process and Fitts' Law modeling to derive estimates of movement dynamics, such as velocity and acceleration, and to assess how task manipulations influence these movement parameters. The statistics derived from the mathematical modeling are then used to parameterize computational implementations of motor control models, which can simulate human performance on interface interactions. These simulations can be directly compared to the human data that they emulate. With this combined modeling approach, we can move toward model-based interface design evaluation with respect to specifications that facilitate natural and effective input behavior.

Mathematical-Computational Symbiosis: Integration and Convergence in Theories of Human Cognition

Gunzelmann, Glenn

Mathematical and computational psychology share a similar vision of creating formal representations of human cognitive capacities and limitations. However, the approaches tend to be applied to different phenomena, leading to a divergence between the communities. Recently, however, there have been examples of integrated mathematical-computational models that are focused on providing more detailed and more comprehensive accounts of complex phenomena. This talk will focus on a particular example – modeling the effects of fatigue on cognition. Mathematical modeling has been applied in this domain for the last two decades to characterize the dynamic fluctuations in alertness and cognitive performance that are caused by time awake, circadian rhythms, and other factors like sleep inertia, light exposure, and caffeine. My own research has leveraged these mathematical modeling in research that has applied computational modeling to understand the consequences of fatigue on performance in complex tasks. The research highlights synergies between mathematical and computational approaches, and demonstrates how the combination of approaches can be used to provide more comprehensive theories of empirical phenomena that bridge levels of analysis.

Submitted Presentations

A Bayesian Assessment of Reproduction

Shiffrin, Richard Martin, and Chandramouli, Suyog

Science has been facing a crisis concerning reproducibility of reported results. Of the host of issues on this topic we focus on just one: Quantitative assessment of reproduction. Even in this limited domain there are many complex issues. Because the concern of reproduction is almost always about some data statistic, S, a Bayesian analysis is best approached with the new Bayesian inference system we have termed BMS*, which infers distributions of data outcomes. Using a hierarchical Bayesian approach we show how can take into account expected differences among studies as well as noise due to limited data in either study. To deal with differences in study size we make inferences about a Minimum Reproduction Unit (MRU) for the statistic S. The MRU is assumed to be independently repeated n1 and n2 times in the two studies. If S1 and S2 are the two observed values, decisions are based on the posterior prediction for the difference S1-S2, based on the posterior prediction(s) for the MRU.

A Bayesian Cognitive Model of Crowds that Opt In

Bennett, Stephen T., Steyvers, Mark, and Mistry, Percy, K

We explore the implications of giving people the ability to opt in. Opting in is the decision to participate in answering a given question. We take the crowd's response as our metric for performance and compare crowds with the ability to opt in and those without. It's unclear to what extent this ability to choose is beneficial or detrimental under this metric. It may be the case that crowds with the ability to choose have the metacognitive ability to select questions for which they have pertinent knowledge, leading to better performance as individuals that leads to better group performance. However, it may also be the case that many questions go unanswered when people have the ability to choose, leading to poor performance on unpopular questions.

In a novel experiment, we aim to answer how participants perform when they can choose. We find that participants do have the metacognitive ability to choose to answer questions they perform well on. However, several questions go unanswered across all participants that can choose. Overall the crowd that can choose outperforms the one that cannot. However, when we consider only a small random subsample of all the participants when forming the crowds, the crowd that cannot choose benefits from answering all of the questions and performs as well or better than the crowd that can choose.

We develop a hybrid approach that maximizes the benefits of the crowd that can choose while minimizing its downsides. Lastly, we consider a Bayesian cognitive model to describe the process by which participants generate their choices and their answers to the questions. We use this model of how the responses are generated to form a better crowd decision given the participants' responses.

A Cognitive Latent Variable of Optimal Stopping Problems

Guan, Maime, Vandekerckhove, Joachim, and Lee, Michael

In optimal stopping problems, people are asked to choose the maximum out of a sequence of values, under the constraint that a number can only be chosen when it is presented. There exists a known optimal solution of the optimal stopping problem to which human performance can be compared. First, we present a hierarchical cognitive threshold model, the bias-from-optimal model, that assumes individual differences in threshold setting are controlled by deviations or biases from optimality associated with intelligence, and is applicable to optimal stopping problems of any length. Next, we present a cognitive latent variable model (CLVM) of the optimal stopping problem, combining the cognitive process model of the task with a latent variable model of underlying structure, relating the optimal stopping task to external measures of cognitive ability and intelligence. Using Bayesian graphical modeling methods, we apply the CLVM model to previous data involving 101 participants with large individual differences in measures of cognitive abilities dimensions and intelligence, who completed two optimal stopping tasks of length 5 and length 10. Our results demonstrate the effectiveness of the CLVM to simultaneously study the individual differences in thresholds that people use across both tasks, and the underlying latent structure relating those task-specific individual differences in deviation from optimality to cognitive ability and intelligence measures.

A Collaborative Project on the Validity of Response Time Data Inference

Dutilh, Gilles, and Donkin, Chris

This project aims to study the validity of inferences that are drawn using different methods of response time data analysis. For this goal, 17 teams of experienced response time data analysts analyzed the same 14 real data sets. In these data sets, we manipulated various properties of participants' speeded 2-choice behavior: ease of processing, response caution, and response bias. The analysts were blind to the precise manipulations when they analyzed the data to draw their inferences. The project shows there is a large variability in the methods that experts choose to apply to analyze these data sets. Not only did analysts apply a wide range of mathematical models (full diffusion model, Wiener diffusion model, linear ballistic accumulator model, EZ diffusion), they also applied a variety of parameter estimation methods (e.g., maximum likelihood, Bayesian, hierarchical or not) and procedures to draw inferences (model selection, parameter inference). Our results show that these "modeler's degrees of freedom" significantly affect the inferences that analysts draw. Overall, the applied methods detect most of the effects induced in the experiments. However, there are consistent discrepancies between various methods of analyses.

A Comprehensive Approach to Evaluating Measurement Axioms in Decision Making

Davis-Stober, Clintin Phillip, Park, Sanghyuk, and Brown, Nicholas

We provide a comprehensive statistical approach for evaluating measurement axioms and similar structural properties of decision making. Our approach uses modern Bayesian model comparison methods to classify individual decision makers according to whether their choices conform to particular sets of measurement axioms, e.g., transitivity and/or double cancellation. Our approach is sensitive to individual differences with respect to the nature of stochastic variability, i.e., simple "errors" versus substantive changes in preference. We model group-level classifications via Bayesian hierarchical models, which allows for evaluating between-group (or between-treatment) differences in the distribution of measurement axiom classifications. We illustrate our approach with several data sets.

A Detailed Comparison of MDFT and MLBA in Multialternative Consumer Choice

Hotaling, Jared M., Rieskamp, Jörg, and Busemeyer, Jerome R.

Many of the choices we make involve multiple alternatives. For example, when buying a new laptop computer a decision maker is faced with many options, varying along attribute dimensions such as price, portability, and computation power. It has long been observed that the likelihood that option X is chosen over option Y often depends on the other options on offer. For instance, a decision maker's preference for a high-end, lightweight netbook over a cheaper midrange laptop can reverse when a third, low price, but bulkier, computer is also considered. Such preference reversals violate a key assumption of utility-based models known as independence of irrelevant alternatives (IIA), which stipulates that the utility of an item is judged independently of the other items in the choice set (Rieskamp, Busemeyer, & Mellers, 2006). These violations of IIA are known as context effects.

Several computational cognitive models have been proposed to account for context effects in multialternative choice. Multialternative decision field theory (MDFT) was one of the first models shown to simultaneously produce the similarity, compromise, and attraction effects (Roe, Busemeyer, & Townsend, 2001). More recently, Trueblood, Brown, and Heathcote (2014) proposed the multiattribute linear ballistic accumulator (MLBA) model as an alternative. Trueblood et al. (2014) argue that MLBA should be preferred over MDFT because 1) it provides a more accurate account of multialternative choice data, and 2) it is more computationally tractable and therefore easier to use.

Although we commend Trueblood and colleagues for developing a new, unique, and quite successful theory of multialternative choice, we contend that these claims are overstated. In this talk, I will present the results from a detailed comparison of MDFT to MLBA using data from a large multialternative consumer choice experiment conducted by Berkowitsch, Scheibehenne, and Rieskamp (2013). Although the models imply quite different psychological processes, we find that both are reasonably successful in accounting for many empirical trends, but also fail to capture other key patterns. Overall, our results suggest that MDFT provides the more accurate account of the data in question. I will examine the strengths and weaknesses of each model, as well as the impact of these results on our understanding of multialternative decision making.

A Factor-Analytic Modeling Approach to ERP Analysis

Sheu, Ching-Fan, Causeur, David, Perthame, Emeline, and Lee, Yuh-shiow

Event-related potentials (ERPs) are recordings of electrical activity along the scalp time-locked to stimulus or response events. ERP studies provide important information about the chronology of mental processes. Because ERP signals are often rare and weak, relative to the large between-subject variability, significance testing of ERP differences across experimental conditions or detecting significant associations between ERPs and behavioral variables of interest poses major challenges for statistical analysis. Noting that ERP time dependence exhibits a block pattern suggesting strong local and long-range autocorrelation components, we propose a factor-analytical modeling of ERP dependence in the multivariate regression framework. Assuming a prior knowledge of the noise-alone intervals, an iterative estimation algorithm is derived jointly for the signal and noise processes. With simulated ERP signals embedded within real ERP noise, the proposed procedure is shown to outperform current methods and is more powerful at discovering time points at which ERPs are significantly different across conditions or are significantly associated with behavioral covariates. The ERP package in R implements the proposed procedure as well as various multiple comparison procedures for ERP analysis.

A Fechnerian Model of Working Memory Confidence

van den Berg, Ronald, and Ma, Wei Ji

Although visual working memory has been studied extensively, it is unknown how people form confidence judgments about their memories. Charles Peirce speculated in 1878 that Fechner's law – which states that sensation is proportional to the logarithm of stimulus intensity – might apply to confidence reports. Based on this idea, we hypothesize that humans map the precision of their working memory contents to a confidence rating through Fechner's law. We incorporate this hypothesis into the best available model of working memory encoding and fit it to data from a delayed-estimation experiment. We find that the model provides an excellent account of human confidence rating distributions as well as the joint distribution of memory precision and confidence. In an attempt to falsify the model, we also consider a flexible family of alternative, non-Fechnerian mappings between working memory precision and confidence. Using formal model comparison, we find that this flexibility does not improve the model fits and thus fails to falsify our model. Furthermore, we propose a neural implementation of the model, in which working memory confidence is a function of neural population activity. We find that this model also fits the psychophysical data well. Finally, we show that jointly fitting memory errors and confidence ratings boosts the power to distinguish working memory encoding models by a factor of 5.99 compared to fitting only memory errors. Our model is the first to jointly account for errors and confidence ratings in visual working memory and could lay the groundwork for understanding its metacognition.

A Geometric Framework for Modeling Decisions among Many Alternatives

Kvam, Peter D

Historically, models of the decision-making process have focused on the case where a decision-maker must choose between two alternatives. The most successful accounts of binary choice and response time, sequential sampling models, have more recently been extended to account for decisions between multiple alternatives. However, most of these accounts must introduce additional assumptions reflecting psychological relationships between alternatives in the choice set. I present a general geometric representation encompassing both relative (diffusion-like) and absolute (accumulator-like) evidence accumulation models of multiple-choice decisions. I use this to illustrate the psychological assumptions they make about the available choice alternatives as well as how they can be analyzed as Markov random walks on a lattice. I then show how the geometric framework can be used as a basis for modeling decisions among any number of alternatives by adjusting the models' assumptions regarding the psychological relationships between choice options. I then apply the framework to modeling behavior in a perceptual task where participants must reproduce the orientation of a noisy stimulus. The study examines continuous analogues of common two-alternative accuracy and response time phenomena, finding empirical support for difficulty or coherence effects, the speed-accuracy trade-off, and starting point biases in evidence accumulation. An inspection of model fits and empirical predictions suggests that it is well-suited to describing behavior on the task.

A Joint Bayesian Model of Extracellular Recordings and Behavioral Data in Mice

Baribault, Beth, and Vandekerckhove, Joachim

Neural decoding models are typically used to reconstruct a stimulus from neural data through recognition of quantifiable patterns in the neuronal response. This is possible because a given neuron will exhibit a different pattern of firing when its preferred stimulus is presented (e.g., a high firing rate) than it exhibits when a non-preferred stimulus is presented (e.g., a low firing rate). If electrophysiological recordings are taken from neurons with different preferences while a stimulus is presented, neural decoding methods may be used to recover the identity of the stimulus from the neural responses across the population.

We apply the theory of neural decoding to the prediction of a behavioral response, rather than the recovery of a stimulus identity, from neural data. Specifically, we develop a novel Bayesian model to analyze extracellular recordings from mouse anterior lateral motor cortex, which is thought to act as an accumulator area for motor responses, during a simple object location discrimination task. The Bayesian decoder model is used to (1) determine the preference of a given neuron from the observed spike count data and behavioral responses, and (2) predict the behavioral response from observed spike count data and previously estimated neuron preferences. The model successfully predicts the behavior of mice from neural data. We discuss how this decoder may be viewed as a generalizable approach to neural decoding in a Bayesian framework.

A Linear Ballistic Accumulator Model with a Fast-Guess Process Accounts for Empirical Findings in the Simon Task

de Hollander, Gilles, Salzer, Yael, Forstmann, Birte, and van Maanen, Leendert

In the Simon task, the speed and accuracy of responses to a relevant stimulus feature, e.g. the color of the stimulus, are influenced by a non-relevant spatial stimulus feature, e.g., that the stimulus is presented on the right side of a central fixation cross. Multiple sequential sampling models have been proposed that can capture this Simon effect on both reaction times and choice proportions. Although some of these models have intuitive appeal, there are associated problems that preclude a robust application to data. For example, the typically large number of parameters leads to overflexibility, and often there is no known likelihood function which makes parameter estimation a difficult challenge.

We propose a modified version of the Fast guess LBA (Noorbaloochi et al., 2015) that does not suffer from the same issues as other models, but can account for the main empirical findings in the Simon task. Firstly, it can account for the occurrence of fast errors in incongruent trials. Second, this model can predict that the difference in RTs between congruent and incongruent trials is smaller for slower RTs ('negative delta plot'; Ridderinkhof, 2004). The model has, like the traditional LBA model, a closed-form likelihood function, which makes it relatively easy to fit to data.

We show that the model can account for data from five different Simon task datasets in both the tactile and visual domain. We also show, through simulation, that its parameters are reasonably well-recovered. Importantly, parameters of the model can be interpreted in a psychologically meaningful way. In addition, the model provides trial-to-trial estimates of how likely it was that a fast spatially-driven response process was active. Finally, trial-to-trial estimates are linked to neural measures of the Simon task to investigate the neural substrate of putative "fast" and inhibitory processes.

A New Model for Obtaining Separate Estimates for Item and Source Information

Chechile, Richard A.

An important problem for the measurement of memory processes is the obtainment of separate storage metrics for item and source information. Existing multinomial processing tree (MPT) models require parameter simplification in order to make the models identifiable. However, the set of simplifying assumptions for the existing model compromise the full generality of having both the item and source measures differing across several sources. A new MPT model is linked to a new experimental procedure that records recognition judgments, confidence, and source recognition. This model is fully general and results in separate measures for item and source information for each source. The model is illustrated by a new experiment that provides validation information for the model.

An Unified Classical/Quantum Framework for Causal Reasoning

Yearsley, James, Trueblood, Jennifer, and Pothos, Emmanuel

Throughout our lives, we are faced with a variety of causal reasoning problems. Arguably, the most successful models of causal reasoning, Causal Graphical Models (CGMs), perform well in some situations, but there is considerable variation in how well they are able to account for data, both across scenarios and between individuals. We propose a framework for causal reasoning based on quantum probability (QP) theory that accounts for behavior in situations where CGMs fail. Whether QP or classical models are appropriate depends on the representation of events constructed by the reasoner. We describe an experiment that suggests the representation of events can change with experience to become more classical, and that the representation constructed can vary between individuals, in a way that correlates with a simple measure of cognitive ability, the Cognitive Reflection Task.

A Parallel Interactive Linear Dynamic Model of the McGurk Effect

Altieri, Nicholas Albert, and Yang, Cheng-Ta

This paper uses a linear dynamic parallel model to quantify audiovisual interactions: specifically, the McGurk effect will be investigated. (This occurs when an auditory syllable /ba/ recorded over incongruent lip movements that produce “ga” typically causes listeners to hear the fusion: “da”). We begin by hypothesizing reasons why certain clinical and hearing-impaired listeners are more susceptible to the McGurk effect; we likewise examine why other populations and individuals are less susceptible to the McGurk effect and typically hear just the auditory stimulus without being influenced by the visual modality. These ideas are accompanied by a mechanistic explanation of integration phenomena including visual inhibition of auditory information, as well as slower rate of the accumulation of inputs. First, simulations of a linear dynamic parallel interactive model were instantiated using inhibition and facilitation to examine potential mechanisms underlying integration. In a second set of simulations, we incrementally manipulated the inhibition parameter to model real data obtained from listeners with autism spectrum disorder. We conclude by advocating the analysis of a listener’s responses to incongruent auditory-visual speech signals to identify perceptual processes that may interfere with integration abilities.

Assessing the Dynamics of Deliberation during Preferential Choice

Pleskac, Timothy Joseph, Yu, Shuli, Hopwood, Christopher, and Liu, Taosheng

Computational models of decision making typically assume as people deliberate between risky gambles they mentally simulate possible payoffs from the options and integrate valuations of these payoffs over time to form a preference. We sought to characterize the properties of this deliberation process. We used the Flash Gambling Task (FGT) where participants make a series of decisions between a certain and an uncertain alternative, which produces normally distributed payoffs. The FGT uses dynamic dot stimuli where each option is represented by an array of randomly positioned dots. The value of each

option at each instant is equal to the number of dots in the display. The key aspect of the FGT is that to form a preference participants are provided with a stream of payoff information from each option. Thus, we made the information stream observable to better understand how the information is used to make a choice. We report two studies. In a first study, we compared deliberation during preferential and perceptual choice. In the perceptual condition the same stimulus was used, but participants made a perceptual judgment based on dot numerosity. Thus, goals in both conditions should be identical. Replicating past results we show a divergence. When the uncertain option had a lower mean payoff, subjects in the gambling condition were more likely to choose the gamble i.e., risk seeking. Fits of a drift diffusion model isolate this difference not to a start point difference, but to differences in drift rates. We go beyond past studies by examining the time-varying contribution of the observed samples on choice. This reverse correlation analysis showed participants were less sensitive to each sample of information in the gambling condition. In a second study, we used these different measures of deliberation to examine how individual differences in this process are related to impulsivity, attitudes about risk taking, and drug and alcohol use. We show that although the deliberation process during the FGT is not related to impulsivity or risk attitudes, aspects of the deliberation process are related to substance use. In particular, alcohol abuse was related to diminished sensitivity to the samples and drug use was related to the relative start point of deliberation. Taken together these results demonstrate the critical role deliberation plays in shaping preferential choice, and helps validate an experimental framework for studying this process.

Bayes Factors for Multinomial Processing Tree Models via Bridge Sampling

Gronau, Quentin Frederik, Matzke, Dora, Boehm, Udo, Sarafoglou, Alexandra, Ly, Alexander, Steingroever, Helen, Marsman, Maarten, and Wagenmakers, Eric-Jan

Multinomial Processing Tree (MPT) models are a popular class of cognitive models for measuring and disentangling cognitive processes that underlie observable, categorical data. MPT models are popular due to their simplicity and they are applied in a number of substantive areas of cognitive psychology such as human memory, visual and auditory perception, and logical reasoning. In many applications, the scientific question of interest is the comparison between two or more (possibly non-nested) models. The Bayesian solution to this problem is to compute the Bayes factor which allows us to quantify evidence for the competing models on a continuous scale. However, in the context of MPT models this is complicated by the fact that there are usually no closed-form solutions to obtain the Bayes factor. We will present a powerful technique called bridge sampling (Meng & Wong, 1996) which, to our knowledge, has not been applied in the MPT context before. Bridge sampling enables accurate computation of the Bayes factor and is fairly easily implemented once posterior samples for the model parameters have been obtained. It is an appealing method because it allows generalization to hierarchical MPT models such as models with participant and/or item effects. We will explain the relevant steps for implementing bridge sampling for MPT models and we will illustrate the method with examples from the MPT literature.

Bayesian Cognitive Models of Metacognitive Judgment and Expertise

Mistry, Percy K, and Steyvers, Mark

Consider the problem of extracting an unknown truth from an aggregate of respondents, where individual respondents may vary in the level of expertise. Various wisdom of crowd approaches have been implemented in literature, including inferring latent expertise based on consensus and coherence. Some approaches, such as the Bayesian Truth Serum involve asking respondents for two judgments, an answer to a particular question, as well as a metacognitive prediction of what proportion of other people would select each answer. Implicitly or explicitly, these approaches make various assumptions about the metacognitive predictions and corresponding underlying processes. The empirical evidence for properties of such metacognitive predictions has not however been explored in detail. In this paper, we implement studies with two alternative forced choice questions with two key objectives. The first is to investigate and model the properties of metacognitive awareness. We show that both item-specific knowledge and general expertise levels can affect the degree of self-centricity that individuals have in imputing one's own knowledge to others. We use a theory-of-mind approach to develop Bayesian cognitive models that can describe the process generating metacognitive judgments and account for observed behavior. The second objective is to test whether signals from metacognitive judgments can be used to infer the latent ground truth. We find that metacognitive judgments do contain some information about the latent knowledge levels of individuals, which can be harnessed to improve predictions based on aggregated responses. We compare different computational approaches, including extending the Bayesian cognitive models, to infer the latent ground truth. The preference of which approach to adopt can be sensitive to environmental conditions such as the base rate of question difficulty and participant expertise levels.

Bayesian Estimation of Messy Stop-Signal Data

Heathcote, Andrew, Hawkins, Guy, and Matzke, Dora

The stop-signal paradigm, where a signal occasionally occurs after a choice stimulus that requires participants to withhold their response, is widely used to estimate parameters associated with inhibitory processing. The delay between the choice and stop signal (stop-signal delay, SSD) is typically chosen with the aim of inducing a signal-respond (i.e., failure to stop) rate around 50%, sometimes using a staircase procedure that increases SSD after a successful stop and decreases it after a failed stop. Unfortunately, gaining good data from this paradigm can be challenging under some circumstances. Participants can fail to comply with task instructions, sometimes ignoring the stop signal ("trigger failure", Matzke, Love & Heathcote, 2016), or over-generalizing stopping, so they fail to respond in the absence of a stop signal ("go failure"). Parameter estimation typically assumes that "go" (i.e., choice) processing is stationary over the course of the experiment, but participants can try to avoid signal-responses, "chasing the staircase" by progressively slowing their responses, or they may speed up in order to quickly complete what can be a frustrating and fatiguing experience. Estimation is also frequently based on only correct choices, even though the go process can produce errors. We develop models based on the Ex-Gaussian distribution (Matzke, Dolan, Logan, Brown & Wagenmakers, 2013)

and the Lognormal Race (LNR, Heathcote & Love, 2012) that allow for go errors, both go and trigger failure, and for the LNR model also proportional linear increases or decreases over the session in the mean and standard deviation of go RT. We investigate the operating characteristics of Bayesian estimation of these models and apply them to a data set in which participants were fatigued.

Bridging Cognitive Modeling and Computational Science: A Mathematical Framework of Qualia Space in a Dual-process Cognitive Model resulting in a Novel Machine Learning Algorithm

Vaughan, Sandra Lee, Mills, Robert F., Peterson, Gilbert L., Grimaila, Michael R., Oxley, Mark E., and Rogers, Steven E.

The phenomenal properties of conscious experiences are created using a vocabulary of qualia primitives. It is theorized that qualia are maximally integrated information structures, i.e., geometric shapes, which can be modeled mathematically, creating qualia space (QS). Qualia are the vocabulary of evoked experiences of consciousness, which includes recalling memories. Memories are an aggregate of elements of similar repeated experiences, as opposed to single episodic recall of sensory data. Consciousness is experienced as a combination of past memories and current experiences integrated into preexisting qualia integrated information structures; simulations of future experiences can also be created from these same preexisting qualia integrated information structures.

In our research, we developed a mathematical framework for maximally integrated information structures in QS. The proposed qualia modeling framework (QMF) employs a dual-process cognitive model that reasons over externally provided sensory data, i.e., observables. The reflective mind, i.e., artificial consciousness, is simulated by conceptual knowledge evoked from QS, and the autonomous mind, i.e., artificial subconscious, is simulated by episodic memories evoked from previously stored sensory data. Our QMF also functions as a supervised machine learning classifier, thus leveraging models of human cognition, specifically consciousness, to advance the computational sciences. Externally provided sensory data can come from various data sets, therefore our formalism is generalizable to multiple domains. Finally, in this research, we applied a Hausdorff metric to Hypernetwork theory measures of eccentricity, resulting in a novel binary distance measure, which advances Hypernetwork theory, and generates an abductive inference.

Cause and Affect

Searcy, Nicholas, Lane, Jonathan D., Rodriguez, Fernando, and Shafto, Patrick

How is judgment influenced by affect? We conducted and modeled two experiments exploring human causal evaluation of affective content. The first (n=633) asked participants to make causal evaluations about a fictional scenario. We altered the perspective (whether ``you have", ``someone has", or ``there is" a gene that might be activated) and the valence (whether activation of the gene results in an increase of ``happiness'', ``sadness'', etc.). We find that Causal Support, a rational Bayesian model,

offers good predictions for causal inferences when the inferences are made from impersonal and third-person perspectives. However, when inferences are made from the personal perspective, people's inferences appear to systematically deviate from the model. This deviation is consistent with a prior expectation that causation is less likely the more negative the effect is. The second experiment (n=325) tests this hypothesis directly by asking participants about their prior expectations. We find that for the first-person (but not impersonal or third-person) perspective, the prior is predicted by the valence of the effect. Together these experiments demonstrate an effect of perspective and valence not previously captured by models of causal evaluation and suggest that these effects can be parsimoniously explained by adjustments to prior expectations.

Clustering Choice Data Using Deviations from the Aggregate Constant Ratio Model (ACRM)

France, Stephen L., and Ghose, Sanjoy

The aggregate constant ratio model (ACRM) is an aggregation of Luce's choice axiom and assumes a situation where the probability of choosing one item over another is not affected by other items in the choice set. This presentation describes a model for utilizing deviations from ACRM choice data to cluster items based on overall choice similarity. The model uses a maximum-likelihood methodology and is fit using a heuristic local search optimization procedure. A variant of the “gap statistic” is used to help choose the number of clusters. A k-fold cross validation procedure is utilized to test the stability of the clustering solutions. Applications to brand switching behavior and to more general psychological choice model scenarios are given. Prior intuition can be tested against the computationally derived clustering solutions using a visual methodology. A computational package, programmed in R, is described.

Cognitive Diagnostic Model for Continuous Knowledge State

Rho, Yun Jin

Cognitive skill diagnostic models (CDM) have gained enormous attention and there have been various models developed in the field of Psychometrics. The CDMs provide information on whether or not a student has mastered each required cognitive skill in problem solving, classifying the students into a cognitive skill mastery group and a non-mastery group for each cognitive skill. The CDMs assume that solving the entire set of problems requires a set of latent skills so that we can have more fine-grained information about problem solvers’ skill levels. Ultimately the CDMs can provide cognitive skill profile for each individual student on their weaknesses and strengths. In this study we proposed variations of DINA (Deterministic Inputs, Noisy “And”-gate) model to explore a different assumption in estimating knowledge states which can be considered as latent skills and to simplify the model with more accurate parameter estimation.

The DINA model defines ideal response patterns to predict problem solvers’ performance from their knowledge states. The ideal response pattern is divided into two states, 1: having mastered all required cognitive skills for particular problems; 0: otherwise. The relationship among slip (the probability that a

person solves a problem incorrectly even though the person has mastered required cognitive skills), guess (the probability that a person solves a problem correctly even though the person has not mastered required cognitive skills), and the ideal response pattern determines the probability to predict a person's solving a problem correctly. When a person has mastered all required skills with no slip probability or has not mastered required skills but with a perfect guess probability, the person can solve a problem with a probability of 1.

The proposed model under an assumption that the knowledge state can be continuous values from 0 to 1 unlike the dichotomous values under DINA allows the ideal response pattern to be continuous values. This proposed model performed better based on smaller RMSE in estimating the parameters for the data generated from continuous knowledge states, compared to the DINA model. We also proposed a model to simplify the DINA model by converting a nonlinear relationship among parameters to a linear form. The simulation studies showed that the linear form model recovered the parameters slightly better than the DINA model.

Concept Learning Difficulty and Processing Fluency across Stages of Classification Learning

Zeigler, Derek E., and Vigo, Ronaldo

Learning difficulty orderings of categorical stimuli have long provided an empirical foundation for concept learning and categorization research. The conventional approach seeks to establish learning difficulty orderings in terms of mean classification accuracy (proportion of correct/incorrect classification responses). However, it is relatively rare that the stability of such orderings is tested over a period of extended learning. Further, research rarely explores dependent variables beyond classification accuracy that may also indicate relative learning difficulty, such as classification response times (RTs). Using a category structure with a robust learning difficulty ordering (e.g. Shepard et al., 1961; Nosofsky et al., 1994; Vigo, 2013; Vigo, Zeigler, & Halsey, 2013; Vigo, Evans, & Owens, 2014) we report the results of two experiments that test the stability of the ordering (in terms of both errors and RTs) over multiple category learning sessions. We interpret the results of both experiments in terms of the Generalized Invariance Structure Theory (GIST; Vigo, 2013, 2014), as well as its core formal mathematical model of classification behavior (the GISTM). Specifically, the results support GIST's invariance–based account of categorization behavior along with its proposal that a process of invariance pattern detection underlies category learning. In particular, we show how the reported results support several principles underlying the theory. Additionally, we discuss how the parametric variant of the GISTM advances our understanding of concept representations over the course of learning.

Constrained Optimization of Measurements: A Model of Information Selection in Categorization

Halpern, David Jacob, and Gureckis, Todd

Selective attention has been a crucial feature in many theories of categorization. In many influential theories (Nosofsky 1986, Kruschke 1992), selective attention is implemented through a set of decision weights such that more relevant features of the category are weighted higher in the final categorization decision. In this project we instead take the view that attention can instead be viewed as a type of information sampling. Under this view, allocating attention to a feature means collecting more information about that feature so as to reduce uncertainty about the exact value that feature takes on. Since certain features may be more relevant to categorization and only a limited amount of information can be collected, an attention allocation is optimal when it maximally reduces uncertainty in the final categorization decision. We present a theoretical analysis, and empirical study, examining how people decide to gather more or less precise information about features prior to making a categorization decision.

Constraining the Variable Precision Model of Visual Working Memory

Taylor, Rob, and Donkin, Chris

The variable precision model provides a persuasive theory for visual working memory performance, and ostensibly provides an explanation for guessing behaviour in both delayed estimation and change detection tasks. However, the flexibility of the model suggests it can potentially mimic a number of guessing processes. Moreover, it has only ever been fit to data from one experimental paradigm at a time, despite the model sharing an identical encoding phase for both types of task. We attempted to constrain the model by fitting it to both delayed estimation and change detection data simultaneously. Our results suggest that the delayed estimation paradigm under-constrains the model, when compared to the change detection paradigm. Moreover, consistent misfits were observed for the change detection data that suggested the need for an explicit guessing process. When a simple, yet explicit, guessing process was added, the misfits were alleviated.

Context-Content Systems of Random Variables: The Contextuality-by-Default Theory

Dzhafarov, Ehtibar, and Kujala, Janne

Contextuality-by-Default is a theory of random variables (r.v.s) identified by their contents and their contexts, so that two r.v.s have a joint distribution if and only if they share a context. Intuitively, the content of an r.v. is the entity the r.v. measures or responds to, while the context is formed by the conditions under which these measurements or responses are obtained. A system of r.v.s consists of stochastically unrelated bunches, each of which is a set of jointly distributed r.v.s sharing a context. The

variables that have the same content in different contexts form connections between the bunches. A probabilistic coupling of this system is a set of r.v.s obtained by imposing a joint distribution on the stochastically unrelated bunches. A system is considered noncontextual or contextual according to whether it, respectively, can or cannot be coupled so that the joint distributions imposed on its connections possess a certain property (such as “identity coupling,” “maximal coupling,” “multimaximal coupling,” etc.). We introduce a general measure of contextuality that makes use of quasi-couplings whose distributions are described by signed measures.

Coupling and Copulas in Multisensory Integration

Colonius, Hans

Psychological data are typically collected under various experimental conditions, e.g. speed vs. accuracy instructions in a reaction time experiment, different numbers of targets and nontargets in a visual search paradigm, or hits and false alarms in a detection task. Data collected in a given condition are often considered as realizations of some random variable(s) with respect to an underlying probability space. Note that a-priori there is no principled way of stochastically relating random variables observed under different conditions. For example, reaction time to a given target with n targets present cannot be observed in the same trial with reaction time to the same target with n+1 targets present, that is, they do not refer to (elementary) outcomes defined in the same probability space. This does not rule out numerically comparing average data under both conditions, or even the entire distributions functions; however, any statistical hypothesis, e.g. about the correlation between the random variables, would be void. The theory of stochastic coupling, together with the concept of copula, provides a principled way to construct joint multivariate distributions for all experimental conditions. The choice of a particular coupling construction, however, may be critical in theory development. This is illustrated here by examples from measuring reaction time in a multisensory integration context (Colonius, 2016).

Cultural Consensus Theory Models for Paired-comparisons

Batchelder, William Howard, and Shramm, Pele

The goal of this project is to expand Cultural Consensus Theory by developing models to assess the hypothesis that a group of respondents share a latent consensus representation of the items in a paired-comparison experiment, and if so to estimate the group consensus. In a paired-comparison experiment, respondents (choosers) are presented with pairs of items from a finite master set, and for each pair they are required to choose the item that exceeds the other on some dimension such as preference, size, or age. Suppose members of a group each provide a single choice for each of the M(M-1)/2 pairs from a master set of M items. We develop models with both strong and weak senses of a consensus item representation. The strong CCT model is an elaboration of Louis Leon Thurstone’s paired-comparison models, where each item is associated with a random variable that is Gaussian with a mean location on the continuum that is shared by all group members. For each pair of items, a chooser samples independent draws from the two associated item random variables, and the item that

is chosen is the one with the largest observation. Unlike Thurstone's models with these assumptions, the variance of an item's random variable is specified to depend on both the chooser and the item. The weak CCT model assumes that the group members share a consensus rank order of the items with no ties. When confronted with a pair, a chooser either gains access to the consensus rank and makes the consensus choice, or the chooser fails to gain access and makes a random guess. The probability of accessing the consensus rank order for a pair is specified to depend on both the chooser and the pair. Properties of the models are presented along with experimental data.

Deconstructing the Transient Nature of Cultural Truth

Alexander, Gregory E, and Batchelder, William H

The purpose of the talk is to utilize methodological and mathematical axioms from an established formal modeling approach to data fusion called Cultural Consensus Theory (CCT) in order to extract a more veridical representation of cultural knowledge. CCT was created in the mid-1980's with the combined efforts of scientists in the fields of Anthropology and Mathematical Psychology. The theory relies on the notion that specific cultural knowledge can be studied by asking relevant test items to informants who share that knowledge. Thus far CCT models have assumed that each informant has a unique but measurable competency to correctly answer questions regarding their cultural knowledge. A consequence of this is that if one informant has a higher competency than another about some aspect of their culture, then they are assumed to exceed the other in competency for all aspects of the culture. A more realistic assumption is that there is a division of labor, where each informant has high levels of knowledge in some areas of their shared culture, but not in all areas. The novel extension will create new specifications of CCT models that allow the estimation of heterogeneous clusters of items and their relationship to corresponding clusters of expert informants. By identifying informant sets corresponding to areas of cultural knowledge, we may be able to better understand the taxonomy of knowledge in a particular culture as well as to reduce uncertainty in the estimation of overall cultural knowledge.

Disentangling the Testing Effect

Lew, Timothy Franklin, Tran, Randy, Pashler, Harold, and Vul, Edward

Research has suggested retrieving material improves memory more than simply restudying. However, it is unknown how this "testing effect" changes the content of memories in a way that facilitates recall. Retrieval practice may help memory by reducing imprecision, decreasing misassociations, or preventing the spontaneous loss of those memories. Here we use a Bayesian mixture model (see Lew, Pashler & Vul, 2015) to disentangle these possible sources of forgetting and ascertain how the testing effect improves memory.

We trained subjects on the locations of 12 objects and later asked them to recall the locations. Subjects first studied the true locations in four cycles of passive presentation. Afterwards, subjects reviewed the objects four times by 1) observing them in their correct locations, 2) recalling their locations or 3) recalling their locations and then receiving feedback (seeing the objects in their correct locations)

(within subjects). Subjects returned after either 2 days or 1 week (across subjects) and recalled the objects' locations.

Retrieval practice with feedback resulted in the best performance. Root mean square error was lowest for the feedback condition after 2 days and even more so after 1 week. We first examined how feedback helped retrieval practice. After 2 days, practice without feedback caused subjects' responses to drift away from the correct locations and closer to their previous responses. After 1 week, previous responses no longer biased new responses, presumably because subjects forgot their previous responses.

We next used a mixture model to estimate how much errors were due to imprecise memories, misassociations and random guessing (spontaneous memory loss). Noise increased over time, and restudy and feedback resulted in memories with comparable precision. Consistent with the patterns of drift, without feedback locations were initially exceptionally noisy but resembled the other conditions after 1 week. Although subjects at first accurately retrieved memories in all conditions, after 1 week the probability of misassociations increased in restudy and no feedback. We observed few random guesses.

Our results suggest that retrieval practice without feedback can cause memories to drift while restudying allows people to form precise memories that are confused with each other. Retrieval practice with feedback is most effective because it allows people to both retain precise memories and maintain associations between those memories.

Dual Processes and Multi-Stage Decision Model Accounts for Framing Effects in Risky Choice Tasks

Diederich, Adele, Trueblood, Jennifer, Wyszynski, Marc, and Guo, Lisa

Framing effects occur when participants exhibit risk adverse behavior in choices framed as gains and risk seeking behavior in choices framed as losses. One prominent approach states that framing effects in risky choice are the result of two different systems of reasoning – one that is fast and intuitive and another that is slow and deliberate (Kahneman & Frederick, 2002). To allow for precise predictions we apply the multi-stage decision model for multiattribute binary choice options (aka multiattribute attention switching (MAAS) model) to the dual process (system) metaphor. Here, the multi-stage decision model assumes a separate sequential sampling process (diffusion processes) for each system. We assume that the intuitive system precedes the deliberate system and attention shifts from one system to the other during one trial. The time each system is considered - the attention time - influences the predicted choice probabilities and choice response times. Drift rates are defined by subjective values of the gambles. Because the systems are characterized as being fast and slow, we expect pronounced framing effects under time pressure. We show data from different labs testing the predictions of the model.

Dynamic Models of Changing Information

Trueblood, Jennifer, Holmes, William, and Heathcote, Andrew

In the real world, people integrate non-stationary information that changes systematically while the decision is in progress. Although theories of decision-making have traditionally been applied to paradigms with stationary information, non-stationary stimuli are now of increasing theoretical interest. We used perceptual stimuli that change at discrete time points during decisions along with cognitive modeling to investigate how the decision process is updated when a stimulus changes. To investigate the underlying changes in the decision process after the stimulus change, we developed a series of Piecewise Linear Ballistic Accumulator models (PLBA). The PLBA is efficient to simulate, enabling it to be fit hierarchically to participant choice and response-time distribution data using probability density approximation (PDA) methods. We similarly develop and fit a Piecewise Drift Diffusion Model (PDDM) to compare and contrast the inferences of the two models.

Enhancing Learning of Natural Categories Through Guidance of Formal Models of Human Classification

Nosofsky, Robert, Sanders, Craig, and Meagher, Brian

A starting point in science education is learning the fundamental categories of the target domain. In the present project, the goal is to use formal models of human classification to enhance learning of rock classifications in the geologic sciences. Application of the models in this complex natural domain requires the derivation of a multidimensional feature-space (MDS) representation for the rock categories. I report on preliminary progress on the application of an exemplar-memory model of classification in combination with a derived MDS representation for the rocks to enhance the teaching of real-world rock categories. Among the goals are to determine: i) the subsets of examples that might serve as optimal training sets for generalization to the full category distributions; and ii) the optimal sequencing and presentation formats of these training examples.

Evaluating the Predictions of Competing Formalisms on a Non-Linearly Separable Learning Advantage in Human Category Learning

Kurtz, Kenneth J., Pape, Andreas D., and Sayama, Hiroki

We investigate category learning through a focus on two category structures used in a canonical demonstration that linearly separable (LS) categories are not learned more easily than non-linearly separable (NLS) categories (Medin & Schwanenflugel, 1981). These structures are the well-known SHJ Types III and IV (Shepard, Hovland, & Jenkins, 1961) leaving out the 000 and 111 items. Recent evidence from a replication study shows not only a lack of advantage for the LS structure, but a reliable advantage in ease of learning for the NLS structure (Conaway, Levering, & Kurtz, in preparation). This is notable since it is rare to find an NLS category structure that is significantly easier to acquire than a

comparable LS structure with the same number of relevant dimensions. Our goal is to evaluate the a priori predictions of a set of competing proposed formalisms (stimulus generalization, complexity, and a novel coherence-based metric) that offer accounts of the relative ease of concept formation. The success of these different accounts in predicting the NLS advantage will be used to draw conclusions about the psychological underpinnings of human concept formation.

Evidence for Scanning along a Temporal Dimension in Short and Long-Term Memory

Singh, Inder, and Howard, Marc

The nature of search processes in memory has been widely studied using various recognition and forced choice paradigms. The relatively well-studied judgment of recency (JOR) task measures order judgments for the past. The classic finding from Hacker (1980) is that the response time varies as a function of the distance to the more recent item but does not depend on the distance to the less recent item. This result suggests a serial self-terminating process operating on a temporally ordered representation. Recently Hintzman suggested that this finding depends on extensive practice with the task. However, we replicated this result in a single session suggesting subjects can scan a temporally ordered representation in short-term memory.

Recent modeling work suggests that memory depends on a scale-invariant timeline of the recent past. In continuous recognition the recency effect manifests as a decrease in accuracy and an increase in response time (RT) with the lag of a repeated stimulus. Continuous recognition of highly memorable pictures repeated at lags from lag 1 up to lag 128 showed that RT increased with lag. Analysis of the RT distributions showed that the non-decision time changed approximately linearly with the log of the recency of the probe item. These results suggest that memories can be accessed by sequentially scanning along a logarithmically-compressed representation of the past that extends several minutes into the past.

Neural modeling suggests that a scale-invariant representation of the past can also be translated to generate a timeline of future events. We introduce a novel judgment of imminence (JOI) task to study temporal order judgments for the future. The JOI task closely parallels the JOR task and allows us to probe the symmetries in the psychological processes that underlie our ability to remember the past and make predictions about the future. Results suggest at least a qualitative similarity between judgments of the past and the future. Further analysis of the reaction time distribution suggests that there is a systematic change in the non-decision time with the scanning distance. Taken together these findings suggest that people have access to temporally-organized representations of the past and the future that, at least under some circumstances, can be scanned to find a target in a memory search.

Exploration of Contextuality in a Psychophysical Double-Detection Experiment

Cervantes, Victor Hernando, and Dzhafarov, Ehtibar N.

The Contextuality-by-Default (CbD) theory allows one to separate contextuality from context-dependent errors and violations of selective influences. This makes the theory especially applicable to behavioral systems, where violations of selective influences are ubiquitous. For a system with categorical random variables there is a principled way, using linear programming, to measure the degree of contextuality in this systems. For an especially important special case of cyclic systems with binary random variables, CbD provides necessary and sufficient conditions for (non-)contextuality, and these conditions are known to be breached in certain quantum systems. We apply the contextuality analysis of systems with binary random variables, both cyclic and more general, to a psychophysical double-detection experiment, in which observers were asked to determine presence or absence of a signal property in each of two simultaneously presented stimuli. The results, as in all other behavioral and social systems previous analyzed, indicate lack of contextuality. We conclude that the role of context in double-detection is confined to lack of selectiveness: the distribution of responses to one of the stimuli is influenced by the state of the other stimulus.

Exploring Haptic Working Memory as a Capacity-Limited Information Channel: An Information-Theoretic Model of Haptic Memory Performance for Object Width

Lerch, Rachel Ann, Cui, Hengjun, Patwardhan, Soham, Visell, Yon, and Sims, Chris

We evaluate a crucial aspect of haptic perception: the ability to temporarily store and manipulate haptic sensory information for the purpose of accomplishing task relevant goals—a capacity termed haptic working memory (HWM). From a computational perspective, HWM requires the interpretation and storage of noisy sensory signals stemming from an environment demanding a diverse variety of perceptual tasks, ranging from proprioception and kinesthesia to tactile sensation, and the estimation of object attributes (size, weight, roughness, hardness, etc.). Despite the importance of HWM, the extent and nature of its limitations are largely unknown. Recent research however, has demonstrated that an information-theoretic analysis is able to provide a quantitative definition of working memory capacity for other sensory modalities (visual), and is able to yield novel predictions for human performance. Whereas vision is recognized for providing highly precise spatial information, the haptic system is especially effective at processing the characteristics of surfaces and objects. Here, we apply the framework of information theory to the analysis of human HWM performance on a psychophysical task for object width. This analysis is framed around rate–distortion theory, a branch of information theory that provides optimal bounds on the accuracy of information transmission subject to a fixed information capacity. We demonstrate that a simple model developed from the mathematical framework of rate-distortion theory provides an excellent account of the empirical data.

Exploring the Time-Based Resource-Sharing Model through Computational Modeling

Glavan, Joseph J, and Houpt, Joseph W

The time-based resource-sharing model (TBRS) conceives working memory as a rapidly switching, serial, attentional refreshing mechanism, continuously combatting the temporal decay of memory traces. Its strongest prediction, that effective working memory capacity is linearly constrained by cognitive load, or the proportion of task time during which maintenance is impeded, has been repeatedly demonstrated in various studies. Mathematical process models have been developed to implement TBRS; however, working memory tasks typically involve both maintenance and processing activities, and these models only minimally address the non-memory segments. We used the Adaptive Control of Thought – Rational framework (ACT-R), to develop an integrated computational model of TBRS that is able to perform both the memory-related portion of a complex span task and the distractor-processing component. We applied this model to previously published data that includes factorial manipulation of cognitive load in two unique dimensions: distractor rate and distractor-task type. Our model expands upon the standard ACT-R architecture by utilizing temporal inhibition and temporal-context association to encode the structure of the target-memory list and to implement an implicit refreshing strategy. The model reproduces group-level trends in working memory span, response time, and cognitive load measures. Further work is required to identify sources of individual differences and to model serial position effects.

Integrated Models of Both Cognition and Electrocortical Activity Predict Human Decision Making

Nunez, Michael D., Srinivasan, Ramesh, and Vandekerckhove, Joachim

Our goal was to test theoretical relationships between cognition and meso-scale neural processes during visual decision making. The influence of trial-to-trial electroencephalographic (EEG) measures on trial-to-trial differences in encoding, decision, and motor response time was discovered in a Bayesian hierarchical framework by finding posterior distributions of the linear effects of single-trial EEG on single-trial diffusion model parameters. We found evidence that trial-to-trial delays in a specific component of the evoked EEG response (negative potentials over parietal electrodes around 200 milliseconds) to the visual signal were positively related to trial-specific “non-decision” times with an almost millisecond to millisecond correspondence. This suggests that some early single-trial electrocortical responses reflect encoding time within subjects. Encoding time was then separated from motor response time, traditionally unidentifiable in a diffusion model, using external EEG measures as data in a second hierarchical diffusion model fit. The veracity of these models were explored by making and testing predictions about the influence of single-trial EEG measures of attention on single-trial encoding and motor response times. Integrated models of both cognition and electrocortical activity are able to predict known and new subjects’ accuracies and reaction time distributions out-of-sample. Future applications of using neural data to constrain cognitive models will be discussed.

Isolating the Effects of Probe Similarity on Processing Stages in Associative Recognition

Zhang, Qiong, Walsh, Matthew M., and Anderson, John R.

In this study, we investigated the information processing stages underlying associative recognition. We recorded EEG data while participants performed a task that involved deciding whether a probe word triple matched any previously studied triple. We varied the similarity between probes and studied triples. According to a model of associative recognition developed in the Adaptive Control of Thought – Rational (ACT-R) cognitive architecture, probe similarity affects the duration of the retrieval stage: retrieval is fastest when the probe is similar to a studied triple. This effect may be obscured, however, by the duration of the comparison stage, which is slowest when the probe is similar to the retrieved triple. Owing to the opposing effects of probe similarity on retrieval and comparison, overall reaction times provide little information about each stage's duration. As such, we evaluated the model using a novel approach that decomposes the EEG signal into a sequence of latent states, and provides information about the number and durations of the underlying information processing stages. The approach uses a hidden semi-Markov model (HSMM) to identify brief sinusoidal peaks (called bumps) that mark the onsets of distinct cognitive stages. The analysis confirmed that probe type affects the durations of two stages corresponding to retrieval and comparison, as predicted by the ACT-R model of associative recognition.

Job Type Predicts the Laterality of the Frontotemporal Lobar Degeneration with Multiple Correspondence Analysis

Yu, Ju-Chi, Beaton, Derek, Spreng, R. Nathan, Levine, Brain, and Abdi, Hervé

Fronto-temporal lobar degeneration (FTLD) —a common cause of dementia—comprises several subtypes that are defined by the origin of lobar atrophy: left-frontal, left-temporal, right-frontal, and right-temporal. Some previous research suggested that the laterality of degeneration is related to the pre-symptomatic abilities of the patient (Mesulam & Weintraub, 1992; Seeley et al., 2008; Spreng et al., 2010). For example, patients whose occupations required high verbal abilities may be prone to develop atrophy in the right hemisphere, and, therefore, it may be possible to predict the variants FTLD of patients from their past occupation. In our study, we re-analyzed data from Spreng et al. (2010) in order to identify the occupational variables related to the type of FTLD. Because these variables are often qualitative or express non-linear effects, we employed factor analytic techniques tailored for these data types: multiple correspondence analysis (MCA) and discriminant correspondence analysis (DiCA). MCA (Abdi & Valentin, 2007; Lebart, Morineau, & Warwick, 1984) and DiCA (Abdi, 2007a) are extensions of simple correspondence analysis (CA)—a technique related to principal components analysis tailored for categorical and contingency data.

From the previously used data, we included the participants whose FTLD can be traced back to a single-region origin. Among the variables, we analyzed a specific subset of occupational variables (from O*Net), which related to economical or physical risk, and communication. The results of MCA showed a

significant lateral effect ($p < .05$) with no lobar effect. The first component explained 60% of the variance and differentiated the low and high categories of the communication-related variables. The second component explained 16% of the variance and differentiated the low and high categories of economical- and physical-job-risk-related variables. Further, we categorized (with DiCA) individuals according to different FTLD subtypes. The results showed main effects of the laterality ($p < .05$) and the region of subtypes ($p < .05$). In addition, a significant region by laterality interaction was found. In conclusion, the results suggested that patients with occupation that involved less communication skills were more likely to develop a left-hemisphere atrophy. Also, patients with occupation that involved less decision making skill were more likely to develop a left frontal dementia than other subtypes of FTLD.

Learning to Search Short-Term Memory: Items or Categories?

Cao, Rui, Nosofsky, Robert, and Shiffrin, Richard

We explore the ways long-term learning improves short-term memory search. In varied mapping (VM) targets on one trial are foils on the next and vice versa; in consistent mapping (CM), targets and foils never change roles. CM training leads to highly efficient search. Two mechanisms may underlie the effect: 'Item Learning' in which each item comes to be associated to the appropriate 'target' or 'foil' response, and 'Category Learning' in which all items come to be coded as members of a category. Categorical varied mapping (CV) allows these to be distinguished: Members of a category have the same role on each trial, but the role switches between trials. Using arbitrary pictures as stimuli we show that, during early stages of practice, item learning and not category learning governs responding in both CM and CV. Using already learned categories of letters and numbers we demonstrate use of category learning. An extension of an exemplar-retrieval model is applied to account for the early stage item learning in the paradigm.

Measuring Subjective Value Functions Across Quantitative Multi-Attribute Spaces

Schramm, Pele

The nonlinearity of people's subjective value function for items defined by continuous quantitative attributes (such as price or distance) is a prominent topic in decision science. In this talk I will introduce psychophysics-style methodology for measuring an individual's personal subjective value function over a continuous space of multiple attributes from paired comparison choice data. The model introduced is able to find nonlinear interaction effects between attributes, i.e. it doesn't assume that the value of an option is merely the sum of the values corresponding to each of its defining attributes. In cases where there isn't a clear improvement in one option over another with respect to all attributes, the model utilizes an assumption which is consistent with Strong Stochastic Transitivity. More specifically, the probability of an agent choosing one option over another is assumed to equal the arithmetic difference in value between the two options transformed by a link function (such as inverse logit or inverse probit). The Value Function can be fit to a multivariate polynomial or other function of choice through either a

MLE or MCMC method. Once the value function is measured, it is thus possible to predict the probability of an outcome of any paired comparison choice between two items in the attribute space, given a reasonable amount of data. Potential applications of this approach, model performance with human data, and usage of the model for measurement of a population's subjective value function will be discussed.

Measuring the Spatial and Temporal Dynamics of Transsaccadic Perception

Wilmott, James, and Michel, Melchi

A growing number of physiological and psychophysical studies have reported that visual information is spatially remapped in a brief interval preceding the onset of an intended saccade. Researchers have interpreted these results as evidence of predictive remapping: an updating of visual or attentional receptive fields in anticipation of a saccade. Recently, this interpretation has been challenged by an alternative hypothesis that any apparent remapping is not predictive, but rather an epiphenomenon of saccadic target selection (Zirnsak & Moore, 2014). We present results from a reverse correlation study of transsaccadic perceptual discrimination designed to gather and evaluate evidence of remapping under either hypothesis. Observers were asked to report the average luminance polarity of a small, flickering Gaussian blob displayed peripherally for 500ms, whose luminance in each 10ms frame was selected randomly. We found that when irrelevant flickering blob stimuli were added to the display, laterally flanking the target at a distance equal to the magnitude of the instructed saccade, observers' reports were influenced by the luminance of the stimulus in a location corresponding to the prospective retinal location of the discrimination target (in a direction opposite the saccadic target). Importantly, information from this location only influenced the decision in the 100ms preceding the onset of the saccade, consistent with perisaccadic remapping. In a subsequent experiment we modified the task by adding additional, intermediate, flankers to better characterize the spatial characteristics of the remapping. We found that the remapping is spatially precise. Of the 4 flankers, only the one consistent with the prospective retinal location of the discrimination target influenced the discrimination in the perisaccadic interval. This result is consistent with remapping that is predictive and attention-based (Cavanagh, Hunt, Afraz, & Rolfs, 2010). We argue that it is inconsistent with remapping due to saccadic target selection.

Measuring The Wisdom of Nations

Landy, David, Silbert, Noah, and Marghetis, Tyler

Assessing and comparing demographic self-knowledge—the knowledge members of a community have about the proportional composition of that community—has important applications in both international quantitative political science and in organizational and cognitive psychology. At the same time, the heterogeneity of different groups raises intrinsic difficulties in comparison. Standard techniques involve comparing estimates made by community members to true demographic

proportions using mean absolute error (Sides & Citrin, 2007; Lawrence & Sides, 2014; Kuklinski, 1999; Ipsos Mori, 2014). These techniques fail when the true proportions of the groups differ, because estimation errors are systematically related to true values (Landy et al, in prep). Worse, large surveys often do not release individual-level data available, making estimation methods that work with mean or median values necessary. We present a measure of self-knowledge based on classical models of risk perception (Gonzalez & Wu, 1994) which is robust to group heterogeneity. We applied a multilevel Bayesian implementation of this model to a large 14 nation survey to evaluate and compare the demographic self-knowledge of different countries. Our results suggest that previous rankings of national ignorance have confounded bias with differences in demographic composition.

Modeling Between-Subject Variability in Decision Strategies via Statistical Clustering: A p-Median Approach

Brown, Nicholas, Park, Sanghyuk, Steinley, Douglas, and Davis-Stober, Clintin

We present a statistical methodology for clustering decision makers according to similar choice behavior. We apply a p-median clustering algorithm that identifies an “exemplar” for each cluster, a decision maker who best represents that cluster. We demonstrate that information about group behavior can be inferred by examining the behavior of each cluster’s exemplar. The method is exploratory, providing information about the prevalence of decision strategies without researchers needing to specify candidate strategies a priori. The method is also very general and can be applied to a wide range of decision-making data structures. We illustrate our method by re-analyzing two existing choice data.

Modeling Categorization by Real-World Perceptual Experts

Shen, Jianhong, Annis, Jeffrey, and Palmeri, Thomas J.

Whereas novices are faster and more accurate to verify category membership at an intermediate level of abstraction, the so-called the basic level (e.g., "Bird"), than at a subordinate level (e.g., "Blue Jay"), experts are equally fast and accurate at the basic and subordinate level. What psychological mechanisms drive these categorization performance differences as a function of perceptual expertise? We addressed this questions by fitting the accumulator/diffusion models of perceptual decision making to accuracy and response time data from a large sample of online participants with varying levels of psychometrically-measured birding expertise who were tested on speeded category verification of birds (expert category) and dogs (novice category) at the basic and subordinate levels. We specifically applied accumulator/diffusion models using a Bayesian hierarchical framework, which provides a powerful approach to estimating model parameters across individuals and conditions. Behaviorally, we observed that the magnitude of the interaction between level of categorization (basic versus subordinate) and domain (bird versus dog) varied with the measured degree of birding expertise. We tested how expertise affects model mechanisms by fitting variants of the accumulator/diffusion models that allowed the expertise index as a covariate in drift rate, non-decision time, bias, and threshold. We found

that the expertise index is a robust predictor of drift rate and to a lesser extent non-decisional time, but not bias or threshold, for decisions made while categorizing birds at the subordinate level. Experts are faster in the subordinate-level categorization in their domain of expertise mainly because of faster evidence accumulation and likely with slightly faster perceptual encoding as well. Our results help to unravel the psychological mechanisms that give speeded object categorization and inform the understanding of individual differences in real-world visual object categorization.

Modeling Choices and Response Times during Reinforcement Learning

Fontanesi, Laura, Gluth, Sebastian, Spektor, Mikhail, and Rieskamp, Jörg

Many decisions we make every day are between options whose value we can only infer through experience (e.g. deciding between two new restaurants in town), and whose value might change through time (e.g. declining quality of a restaurant we already know). These decisions are usually studied in the lab within the feedback paradigm. In this paradigm, participants make repeated, consequential choices between different options. Reinforcement-learning (RL) models are typically used to describe and explain the updating of beliefs about the value of the options.

RL models typically do not take response times (RTs) into account. However, RTs can provide a better understanding of the mechanisms underlying the decision process (e.g. the trade-off between accuracy and speed of decisions). Moreover, RTs impose additional restrictions on choice probabilities and can be more sensitive to some experimental manipulations thus improving identifiability, a problem commonly encountered with RL models (see Gershman, 2016, JMP).

Sequential sampling models (SSMs) of decision-making have been very successful in predicting both accuracy and RTs in choices between alternatives in various domains (e.g. perceptual, preferential, social). However, very few attempts have been made to extend these models to the feedback paradigm (e.g. Frank et al, 2015, J Neurosci).

In a series of experiments, we attempt to develop a new model to predict accuracy and RTs in the feedback paradigm and validate it with neuroimaging data.

The central goals of this project are: (1) to propose a new combined RL-SSM and show its fits to behavioral data; (2) to show how, taking the reward signal into account, we can have better trial-by-trial predictions of accuracy and RTs, compared to a standard SSM; (3) to show reaction-time effects in a RL task with 4 options with different mean values, that are not evident when looking at accuracy only; (4) to show how our model is able to capture these effects, improving the understanding of the decision process in this task; (5) to show how our model can be extended to fit behavioral data in a dynamic environment (i.e. in which the mean value of the options changes throughout the experiment).

Modeling Continuous versus Discrete Information in Recognition Memory

Starns, Jeffrey, and Ma, Qiuli

A critical goal for memory research is understanding the interplay between systems that retrieve information and systems that use this information to make decisions. For example, in a recognition task information retrieved from memory must be used to decide if a word was or was not previously studied. At the broadest level, the decision process can receive either discrete or continuous information from the memory process, and models assuming both of these options have been successfully applied to recognition data. We explored discrete and continuous models in a recognition paradigm in which participants responded both before and after they saw each test word (so the initial responses had to be guesses). Discrete models include parameters for how often people guess each available response when memory retrieval fails, and explicit guesses provide a direct test of these assumptions. Additionally, the continuous and discrete models make different assumptions about the time course of memory decisions, and we tested these accounts with response time data.

Modeling Memory Dynamics in Visual Expertise

Annis, Jeffrey, and Palmeri, Thomas

The development of visual expertise is accompanied by increases in visual object recognition performance within the expert domain (e.g., Curby & Gauthier 2007, 2009; Evans et al., 2011). In the current study, we investigated the relationship between changes in expertise and recognition via underlying cognitive mechanisms. Participants with a range of birding expertise were recruited and tested on memory for birds (expert domain) and cars (novice domain). First, a standard measure of expertise was derived from performance on a 1-back subordinate matching task in which participants had to determine whether the bird or car species presented on the current trial was the same or was a different species as the one presented on the previous trial. Then participants performed a continuous recognition task in which, on every trial, the participant was presented with an old or new item and the task was to distinguish between the two. The number of intervening items between the successive presentation of a given item (i.e. lag) and the image type (bird or car) were experimentally manipulated. Memory performance was modeled with a Bayesian version of the Linear Ballistic Accumulator model (LBA; Brown & Heathcote, 2008) using performance on the matching task as a covariate on parameters corresponding to drift rate, response caution, and non-decision time. There was an expertise x category interaction on drift rates such that expertise was positively correlated with increases in the ease with which bird images but not car images were recognized as old or new. Expertise did not interact with category for any other LBA parameter. Having localized changes in recognition performance that accompany changes in visual expertise to drift rates, we then developed a model of drift rates, which was based on the Exemplar Based Random Walk (Nosofsky & Palmeri, 1997; Nosofsky et al. 2014). The model assumes that memory strength is a decreasing power function of lag and that similarity is a function of the match between the test item and the stored exemplars. The overall activation of a given

test item is the product of the memory strength and the similarity. This activation is assumed to drive the accumulation process via the drift rates in the LBA. Expertise was found to be associated with overall increases in memory strength, decreases in memory decay, and increases in the distinctiveness of stored exemplars.

Modeling Mindless Choice

Choi, Seo Wook, Craigmile, Peter, Peruggia, Mario, and Van Zandt, Trisha

Experimental participants, usually young, impatient and, above all, human, sometimes do not pay attention to the task that experimenters ask them to perform or, sometimes, perform at a level that is below their best. Researchers often employ sophisticated data preprocessing techniques to partition "good" data from "bad" data for the purpose of discarding observations that did not arise from the process under study. Such preprocessing is problematic for two reasons. First, deciding which data are "bad" requires the application of ad hoc criteria that introduce bias into the analyses that follow. Second, "bad" data may arise not from a participant's failure to pay attention, but from the participant's inability to perform the task for reasons that may be of theoretical interest. Discarding data, then, wastes time, money and potentially useful information.

In this project we describe an alternative to discarding data that involves extending standard models of performance so that they can explain how task-unrelated responses are generated. To demonstrate our approach, we present an expanded signal-detection model that incorporates a Markov processes over responses and apply it to data from a simple choice task. We fit a Bayesian hierarchical version of this model that accounts for both stimulus-induced and stimulus-independent responses and that eliminates the need to discard observations.

Modeling Number of Answered Items in Large-Scale Online Surveys

Okada, Kensuke, Lee, Michael D, and Vandekerckhove, Joachim

Online surveys have been used across a range of disciplines in psychology. Surveys typically consist of multiple pages, each of which contain multiple measurement items. Survey respondents do not necessarily answer all the items. Instead, for a variety of reasons, they may quit the survey at some point, and they also may skip some of the items leading up to that point. The objective of this study is to propose a statistical model that explains survey-answering behavior, by modeling how many items an individual completes. The two important assumptions of our model are: (1) the number of answered pages follows a censored geometric distribution, which is censored at the final survey page, and (2) given the number of answered pages, the number of answered items follows a binomial distribution with some fixed probability of answering. Our model also considers a mixture component reflecting the effect of instructions. We implemented the proposed model using Bayesian methods and applied it to data collected in a large-scale online personality survey. We demonstrate that our simple two-stage model is able to provide a good account of the data, even though it makes only simple assumptions about individual differences. We also consider an extension of the model, which explicitly incorporates a

decrease in the probability of answering questions as more pages are accessed, and show that this captures one qualitative feature of the data not well accounted for by the original model. We conclude by discussing other model variants and potential applications.

Modeling the Structure of People and Items in Ranking Data

Lee, Michael David

Item-response theory is a central model in psychometrics because it neatly separates binary choice data into item-related and person-related properties. We adopt the same approach to the more complicated and richer expressions of knowledge provided by ranking data. We use a simple Thurstonian approach as a basic measurement model that separates ranking data into item location and person expertise. From this basis, we consider a series of hierarchical and latent-mixture extensions, relying on the ability of Bayesian inference to maintain coherent inference. The models developed are applied to real-world data to tackle problems like identifying those people who know rather than estimate answers (e.g., are there people who knew by heart the order of the US presidents?), relating expertise to demographics (e.g., do females or males make better predictions about the NFL?), finding subgroups of people with different latent rankings of the same items (e.g., do groups of people have different preferences for the months of the year?), and identifying polarizing items that some people rank much more highly than others (e.g., which new TV shows do people either love or hate?).

Neural Weber-Fechner Representations as an Adaptive Response to an Uncertain World

Howard, Marc, and Shankar, Karthik

The Weber-Fechner law describes the psychological space in many experiments involving perception of one-dimensional physical quantities. In cases where the physical quantity is represented by multiple different receptors, these receptors appear to asymptotically obey what we refer to as Weber-Fechner scaling. A set of receptors are said to lie on a Weber-Fechner scale if their receptive fields are equally spaced and of equal width on a logarithmic scale. Weber-Fechner scales for neural receptors naturally lead to perceptual Weber-Fechner law behavior.

Is Weber-Fechner scaling merely a consequence of constraints in brain development that would not apply to the design of artificial neural systems? Some authors have hypothesized that Weber-Fechner scaling follows from an assumption about the statistics of the natural world. These are important questions that would inform how to go about designing artificial neural systems. We show that in fact Weber-Fechner scaling is an adaptive response to a world with unknown properties. Weber-Fechner scaling enables a set of receptors to convey the same amount of information about functions in the world of very different unknown scales. In this way, Weber-Fechner scaling uses resources efficiently and leaves the brain equally well-prepared to respond to whatever kind of world it finds. Artificial neural systems that must flexibly respond to a wide range of circumstances should be designed to implement Weber-Fechner scaling.

Finally we note that in general Weber-Fechner scaling poses a significant computational challenge for mechanistic neural models. Variables that cannot be represented simply by designing a sensory receptor, such as time, space and numerosity, require a non-trivial solution. Recent work arguing that the brain computes the Laplace transform of functions of time, space and numerosity provides a solution to this problem.

Noisy Parameters in Risky Choice: A Cautionary Note

Bhatia, Sudeep, and Loomes, Graham

In this paper we examine the effect of variability in model parameters on the predictions of expected utility theory and cumulative prospect theory, two of the most influential choice models in decision making research. We find that zero-mean and symmetrically distributed noise in the underlying parameters of these models can systematically distort choice probabilities, leading to false conclusions. Likewise, differences in choice proportions across decision makers might be due to differences in the amount of noise affecting underlying parameters rather than to differences in actual parameter values. Our results suggest that care and caution are needed when trying to infer the underlying preferences of decision makers, or the effects of psychological, biological, economic, and demographic variables on these preferences. These results also raise questions about the use of deterministic models as theoretical tools for the study of preferential choice.

Nonparametric Bayesian Dynamic Systems Analysis applied to a Large Eyetracking Corpus

Houpt, Joseph W., and Frame, Mary E.

The first stage of analyzing eye-tracking data is commonly to code the data into sequences of fixations and saccades. This process is usually automated using simple rules for classifying ranges of the time series as either of the two types, such as “if the rate of change of the fixation location is less than some pre-determined threshold, then code as a fixation; otherwise code as a saccade.” More recent approaches have attempted to include additional eye-movement categories in automated parsing algorithms, particularly glissades (cf. Nyström and Holqvist, 2010), by using time-varying, data-driven thresholds. We propose to further extend this approach by applying the Beta Process Hidden Markov Model (BP-HMM; Fox, Sudderth, Jordan, and Willsky, 2009). The BP-HMM offers two main advantages over existing frameworks. First, it provides a statistical model for the classification rather than just a single estimate. Second, the BP-HMM uses a latent process to model the number and nature of the types of eye-movements and hence is not constrained to the two (or three) predetermined types.

We applied the BP-HMM to a subset of data from the DIEM project, a freely available large scale corpus of thousands of scan paths recorded from participants watching short video clips (Mital, Smith, Hill, & Henderson, 2011). Based on these data, the BP-HMM was able to distinguish among saccades and fixations (and blinks/errors/etc.) and generated subcategories including varying lengths of eye-movements (i.e., it was able to differentiate between glissades and saccades).

Another feature of this model that is particularly of value in cognitive modeling is that it can be trained using a sample of videos from the DIEM database and this parameterization can be used to classify a batch of new similar stimuli, either from the database or collected in a separate study. Alternatively the model can be used strictly to classify eye movements in a dataset and these movements can be the basis for further analyses such as correlating eye movement sequence type with stimuli (image or video) characteristics.

Normative Theories of Working Memory and Attention

Ma, Wei Ji, van den Berg, Ronald, and De Silva, Nuwan

The precision with which items are stored in working memory declines rapidly with the number of remembered items (set size). Current models of working memory describe this decline as the inevitable consequence of a limit on the amount of available memory resource. I will present an alternative view, in which the decline is the outcome of a normative strategy that balances two conflicting goals: keeping memory errors small and spiking activity low. We formalize this idea in a three-parameter model and find that it accounts well for data from six benchmark delayed-estimation experiments. Moreover, the dependence of precision on set size in the normative model is close to the best-fitting relationship in a completely unconstrained model. We critically evaluate the main assumptions of the normative model and test it against several alternative models. In addition, we show that the normative framework also accounts for data from two change-detection experiments. Finally, we examine the general conditions under which we predict a decrease of memory precision with increasing set size. Our results suggest that the set size effect on working memory precision may not truly be a limitation, but rather the outcome of an optimization strategy.

Next, we consider situations in which the items in a display have unequal levels of importance, as would be the case in a spatial cueing experiment. We again ask a normative question: how should attentional resources be allocated to maximize performance? We derive the optimal solution for any set of probing probabilities. We find that the intuitive strategy of allocating resource in proportion to the probing probabilities is in general not optimal. In particular, in some tasks, if resource is low, the optimal strategy involves allocating zero resource to items with a nonzero probability of being probed. We fitted three models to two cued delayed-estimation data sets: the variable-precision noise model combined with optimal and proportional allocation strategies, and the slots-plus-averaging noise model combined with the optimal allocation strategy. The first of these models best described the data. Our work opens the door to normatively guided studies of attentional allocation.

Not Quite Intuitive Behaviorists: Teachers Use Rewards and Punishments Communicatively and Not as Reinforcement

Ho, Mark K., Littman, Michael L., Cushman, Fiery, and Austerweil, Joseph L.

Parents praise and scold their children; dog trainers give their dogs treats and (sometimes) electric shocks. In interactions with other agents, people often use rewards and punishments in order to teach

behaviors, a process often known as teaching by evaluative feedback. But how do people use evaluative feedback? That is, how do teachers attempt to use rewards and punishments to modify a learner's behavior?

Operant conditioning theory and formal reinforcement learning models posit that organisms learn behaviors that maximize reward. This suggests one possibility: people are 'intuitive behaviorists' who structure their rewards and punishments such that a reward-maximizing agent can learn a target behavior. To test this hypothesis, we had participants train virtual agents who were either pre-programmed to improve over time or modified their behavior in response to feedback. We used several learning algorithms, including model-based and model-free reinforcement learning algorithms as well as ones that inferred communicative intent via Bayesian updating. These learning agents were visually presented as dogs or children in a small 3x3 gridworld, and participants were instructed to use rewards and punishments to train the agents to reach a goal state along a specific path.

Contrary to the intuitive behaviorist hypothesis though, people regularly fail to provide rewards and punishments in a manner that would be effective for teaching reward-maximizing learners. Instead, people use evaluative feedback to communicate information about the 'correctness' and the future expected reward of an action. These results indicate that even when teaching with rewards and punishments, communicative intent plays a central role in pedagogical interactions. Evaluative feedback is thus closely related to other forms of human pedagogy such as teaching and learning by example, by imitation, or by instruction, suggesting that these phenomena all share the same underlying socio-cognitive mechanisms.

On the Importance of Avoiding Shortcuts in Modeling Hierarchical Data

Boehm, Udo, Marsman, Maarten, Matzke, Dora, and Wagenmakers, Eric-Jan

Psychological experiments often yield data that are hierarchically structured. Popular shortcut analysis strategies that fail to properly accommodate this hierarchical structure can result in biased conclusions. To gauge the severity of these biases, we conducted a simulation study in which we generated realistic response time data for a two-group experiment. In line with well-established theoretical results, our simulations showed that Bayesian and frequentist analyses that ignore the hierarchical data structure and rely on participant means are biased towards the null hypothesis. Analyses that take a two-step approach, submitting participant-level estimates from a hierarchical model to follow-up tests are biased towards the alternative hypothesis. Only fully hierarchical analyses of multilevel data lead to correct conclusions. We discuss the relevance of our results to clinical and neuropsychological studies that rely on Bayesian hierarchical parameter estimation.

On the Relationship Between Reward Rate and Dynamic Decision Criteria

Boehm, Udo, van Maanen, Leendert, Evans, Nathan, Brown, Scott, and Wagenmakers, Eric-Jan

For decades sequential sampling models have relied on the standard assumption that decision makers set a fixed criterion before the decision process commences and maintain the same criterion throughout. Recently a number of authors have challenged this notion and have suggested that decision makers become increasingly impatient as they devote more time to a decision, successively lowering the amount of evidence they require for a decision. This impatience component of the decision process is mostly motivated through the argument of reward rate maximization. However, most studies supporting the impatience component do not experimentally manipulate or control rewards and punishments. We use dynamic programming and simulation methods to show how different payoff schemes influence expected rewards under constant and dynamic decision criteria. In our preregistered experimental study we systematically manipulate how decision makers need to adjust their decision criterion to maximize rewards. Moreover, we utilize an expanded judgment task in which the evidence decision makers have acquired when committing to a decision can be directly computed, thus allowing us to visualize participants' decision criterion.

Optimally Weighting the Crowd

Merkle, Edgar, Saw, Geoff, and Davis-Stober, Clintin

We investigate methods for weighting each forecaster for the purpose of aggregation, where the weights are optimized to minimize the squared distance between the aggregate forecast and the ground truth. Davis-Stober et al. (2015; Decision Analysis) theoretically showed that these weights depend on a variety of forecaster traits, including bias, noise, and forecaster covariances (both between one another and with the ground truth). In this paper, we propose a model for estimating these traits and for obtaining optimal weights from real data. The model is similar to established cultural consensus models, latent truth models, and traditional factor analysis models. Through simulation and real data, we show that the optimally-weighted average forecast stemming from the proposed model outperforms other aggregation methods, including the unweighted average and model-based estimates of the ground truth.

Parainformative and Serioinformative Categorization of Integral Dimensional Stimuli

Doan, Charles, Vigo, Ronaldo, Zhao, Li, and Barcus, Karina-Mikayla

Nosofsky and Palmeri (1996) studied categorization performance on the family of category structures corresponding to four objects defined over three binary integral dimensions (i.e., hue, brightness, and

saturation). In their experiment, they observed an ordering that is significantly different to the well-known difficulty ordering of these structures when the stimulus dimensions are separable (e.g., color, shape, and size). In this paper, we investigate the same family of structures involving integral dimensions from four different perspectives: 1) the approach taken by Nosofsky and Palmeri where stimuli are generated using a multidimensional scaling (MDS) procedure and the classification task is serioinformative (i.e., the stimuli are shown one at a time during the learning phase for a few seconds each followed by corrective feedback), 2) the parainformative approach taken by Vigo (2013), where stimuli generated by the same procedure are shown all at once during the learning phase without corrective feedback, and 3) using these serioinformative and parainformative approaches on integral dimensional stimuli generated by a significantly different method from the aforementioned MDS approach. We then attempt to account for the four observed orderings with Generalized Invariance Structure Theory (Vigo, 2013, 2014, 2015) and its core model, the GISTM, as well as with other formal models of concept learning difficulty.

Parallel Facilitatory Retrieval of Item and Associative Information from Event Memory: Insights from Systems Factorial Technology

Cox, Gregory Edward, and Criss, Amy H.

The processes by which item and associative information are retrieved from memory, and the extent to which they may interact dynamically, have yet to be fully characterized, impeding the development of theories of episodic memory. To address this, we present a novel application of Systems Factorial Technology (SFT; Townsend & Nozawa, 1995) to recognition memory. These analyses establish that item and associative information are retrieved in parallel, ruling out strictly serial models in which item information is retrieved before associative information. Specifically, recognition responses are made by pooling together matching item and associative information into a single channel which races against two channels corresponding to mismatching item and associative information. These insights were based on the application of hierarchical Bayesian models of response time distributions and on novel simulations that extend SFT measures into domains with both high error rates and high degrees of potential channel interaction. Our conclusions are verified by Bayesian model selection among different Linear Ballistic Accumulator (Brown & Heathcote, 2008) architectures at both individual and group levels.

Peeks and Keeps: Optional Risk Decisions from Experience

Phillips, Nathaniel David, Neth, Hansjoerg, Gaissmaier, Wolfgang, Navarro, Daniel, Newell, Ben, and Rieskamp, Joerg

Critical tasks from both our evolutionary history (e.g.; food foraging and mate search) and our modern digital age (e.g. stock investing), require people to make decisions from experience – where decisions are based on limited information discovered via active search. The most commonly used experimental paradigms for studying decisions from experience are the sampling paradigm and the n-armed bandit.

However, these paradigms ignore a critical aspect of many real-world decisions from experience tasks. Specifically, in many real-world tasks, decision makers can decide how much risk they are willing to entail during search. On the one hand they can engage in low-risk search that provides information without the risk of losses. For example, a stock investor can study a market without actually investing. On the other hand, they can engage in high-risk search that provides both information and potential resource gains or losses. For example, the stock investor could at any time decide to actually invest her money while continuing to learn. We call these tasks, where decision makers actively decide how much risk to take during search, optional risk decisions from experience (ORDFE).

How, and how well, do decision makers alternate between high and low risk search in ORDFE? In order to answer this question, we developed a new experimental paradigm called Peeks and Keeps. Peeks and Keeps is an extension to the n-armed bandit and sampling paradigm that gives decision makers the opportunity to decide for themselves how much risk they are willing to take during search.

In both simulations, and 3 empirical studies, we used Peeks and Keeps to test how well several candidate cognitive model can describe ORDFE behavior. Each model contains three sub-modules which determine direction of search ("Which option do I select?"), search action ("Do I engage in high-risk or low-risk search?"), and impression updating ("How do I update my impression of the option given what I've seen and how much risk I took?"). The models differ both in how these sub-modules are individually defined, as well their sequential order. Using Bayesian strategy classification techniques, we find credible individual differences in the use of these models. Moreover, model use is correlated with separate measures of decision making styles (e.g.; numeracy). Finally, we define the ecological fit between models and decision environments.

Phonetic Information Transmission in the Perception of Speech Masked by Multi-Talker Babble

Silbert, Noah Haskell, and Zadeh, Lina Motlagh

Speech communication often occurs in the presence of multiple competing speakers. One theory of noise-masked speech perception holds that listeners integrate “glimpses” of target speech (i.e., spectro-temporal segments of the target that have more energy than the noise). Previous work has shown that the proportion of glimpsed target speech predicts intelligibility (Brungart, et al., 2006, J. Acoust. Soc. Amer.) and that an automatic speech recognition system trained on glimpses approximates listener accuracy as a function of the number of babble talkers (Cooke, 2006, J. Acoust. Soc. Amer.). In this project, we used machine learning classification models to analyze the information available in glimpses and full (target + noise) auditory representations of babble-masked speech. Regularized Linear Discriminant, Support Vector Machine, and Naive Bayes classifiers were trained on vectorized auditory representations of babble-masked CV syllables (with C = t, d, s, z, and V = a). The machine learning models outperformed human listeners substantially (>70% vs 54% accuracy, respectively). Analysis of predicted confusion patterns indicates that the Naive Bayes model most closely approximates human error patterns. The effects of variation in the local and absolute thresholds for glimpse calculation will be explored with respect to overall accuracy and error pattern prediction in these machine learning

models. We will also discuss the prospects for using these results to constrain higher-level models of perception and response selection (e.g., general recognition theory, the MDS-choice model).

Poor Optimizers, Worse Satisficers

Orquin, Jacob L., Bagger, Martin P., and Perkovic, Sonja

As decision makers, we regularly face large or even virtually unlimited numbers of choice options from which we wish to find an option that satisfies one or more criteria. Often the boundaries of the distribution are unknown, e.g. when searching for a cheap product we may not know the price of the cheapest product in the available set of options. When boundaries are unknown, an optimizer must search all options to identify the best possible option, but as the set size increases optimizing becomes very costly in terms of time and effort. A better solution is therefore to satisfice that is, to settle for any option that meets an aspiration level. However, choosing an aspiration level requires knowledge about the distribution, which we may not have. Simulating the opportunity cost of partial search, i.e. the price distance between the cheapest option in the total set and the cheapest option in the set of searched options, we find that satisficers can perform well without an aspiration level by setting a search limit instead. Using a beta distribution to simulate environments with normal, uniform, u-shaped, right- and left-skewed price distributions we compute the opportunity cost of limited search as the set size increases. We find that a limited search rule loosely defined as 'search at least five, but no more than ten options' on average identifies an option in the best 10% of the distribution. The rule is independent of the set size and holds for most environments, except for skewed distributions where good options are rare. When distribution boundaries are unknown satisficers will therefore benefit from using a limited search rule while optimizers must search exhaustively. We test whether decision makers adapt to inferential vs preferential tasks by applying exhaustive or limited search. In Study 1 (N = 72) we vary the number of options and in Study 2 (N = 71) the number of attributes for inferential and preferential decision tasks. Search rules are modeled from eye movement recordings. In both studies, we find substantial heterogeneity in search rules, but no effect of task on search rule selection. In Study 1 only five participants applied exhaustive search and of these only one was in the inferential condition. No participants searched exhaustively in Study 2. In general, it holds for both studies that participants searched too little to perform well as optimizers yet searched too much to perform well as satisficers.

Prospect Theory is enough

Tripp, James, Stewart, Neil, Sanborn, Adam, and Noguchi, Takao

Are the outcomes and probabilities of risky prospects multiplied or added together during decision making? Many descriptive models of risky decision making, such as cumulative prospect theory, assume people multiply transformations of outcomes and probabilities. However, people add attribute values together in many decision making tasks, such as impression formation and attractiveness judgments (even of gambles). Adding attribute values is at the core of the normative weighted additive models of multiattribute choice. We examine the evidence for adding and multiplying in two previously collected

data sets by estimating the parameters of a generalized version of cumulative prospect theory where adding and multiplying are special cases.

Psychophysical Judgments of Binary and Unary Intensity Domains: Theory and Evaluation of Data

Steingrimsson, Ragnar

A central observation of Luce's (2012, Psychological Review, 119, 373-387) iteration of his theory of global psychophysical judgments is that perceptual domains of intensity fall into two distinct categories. One concerns inherently binary (2-D) stimuli, e.g., those received by the two eyes or ears. The other involves unary (1-D) stimuli, e.g., attributes such as time, linear extent, vibration, and money. Together the 1-D and 2-D domains are exhaustive for the intensity domains and thus the two associated theories, together, constitute a complete theory of intensity judgments. The axioms underlying these theories lead to polynomial-additive representation of subjective summations. In the 2-D domains, empirical results force a parameter δ = 0 leading to purely additive representation. In contrast, for the 1-D theory δ = -1,0,1 all appear possible. The observation emerges from overlooked solutions to Hölder's (1901) theorem. These solutions do not seem to matter in the physical sciences, hence they may have been overlooked, but they do matter in psychology. In the 1-D domains δ = -1,1 constitute two additional solutions to Hölder's theory, leading to three distinct solutions for the psychophysical function. In utility, these lead to a prediction of three distinct types of observers. While the 2-D domain has been somewhat extensively explored empirically, the 1-D domains have not. In the 2-D domains, Stevens' power law is typically found to be a good fit to data, but predictions about the 1-D domain suggest certain specific exponential forms to be better fit. Here several extant data sets are analyzed with the results suggesting that predictions of the 1-D theory are plausible. These results have substantive implication for psychophysical as well as utility research and call for principled exploration of the axioms underlying the 1-D domains.

Quantifying Statistical Support for Causal Claims: A Case Study on the Possible Fungal Etiology of Alzheimer's Disease

Etz, Alexander, Marsman, Maarten, Gronau, Quentin, Grasman, Raoul, and Wagenmakers, Eric-Jan

The discovery of causal relations is of key importance in any scientific field, but it is not always clear exactly how researchers can provide statistical support for such claims. Recent research suggests a possible fungal etiology of Alzheimer's Disease (AD), implying that fungal infection in the central nervous system is a necessary and sufficient condition for the development of Alzheimer's Disease. We show how to construct statistical models that encode various relationships between fungal infection and AD, such as: (1) fungal infection is necessary and sufficient for AD, (2) fungal infection is necessary but not sufficient for AD, (3) fungal infection is related to AD but neither necessary nor sufficient, etc.

We employ Bayes factors to quantify how much statistical evidence recent findings provide in favor of the causal versus non-causal models.

Representations of Space and Time in the Brain

Tiganj, Zoran, Shankar, Karthik, Hasselmo, Michael, and Howard, Marc

It is well known that, all things being equal, the accuracy of memory is better for events that took place at more recent past than at more distant time points. We present a biologically plausible computational framework that can account for this gradual decay of memory over multiple seconds. The framework relies on sequentially activated cells that constitute an internal timeline. Sequentially activated neurons, referred to as time cells, have been observed in a variety of brain regions in rodent and non-human primate models. According to the hypothesis, peaks of neural activations are log spaced in time and their widths scale also as a log of time, obeying the Weber–Fechner law. These properties are qualitatively consistent with neural time cells. Mathematically, the equations for time can be generalized to position if cells can be modulated by the animal's velocity. This allows for a formal model of place cells, a well-known neurophysiological phenomenon where neurons fire in a circumscribed region of allocentric space during navigation around an environment. We present a biophysical model for implementing the key equation necessary for generating time- and place-cells. This model uses known properties of neurons in the medial temporal lobe accompanied by reasonable assumptions. An internal timeline makes various useful computations easily achievable. For instance, translation of the timeline enables prediction of the future; translating a spatial representation enables imagined exploration of novel paths. This capability allows estimation of expected reward and could serve as a basis for novel reinforcement learning models as well as for models of spatial navigation.

Response Inhibition in Sleep Deprivation: Failing to Stop or Failing to Start?

Hawkins, Guy, Mittner, Matthias, Matzke, Dora, Boekel, Wouter, Forstmann, Birte, and Heathcote, Andrew

Sleep deprivation has a profound detrimental effect on many aspects of cognitive control, including response inhibition. Response inhibition is the ability to monitor and inhibit inappropriate responses. Response inhibition is commonly measured with the stop-signal task, which requires participants to occasionally withhold a response in a choice task (go task) when presented with a stop signal. Performance in the stop-signal task is often modeled as a race between go and stop processes: if the go process wins a response is produced, if the stop process wins a response is inhibited. Recent developments in cognitive modeling of response inhibition allow for a finer-grained distillation of inhibitory processing than conventional models, though these methods have not been applied in the context of sleep deprivation. Here, we used the new methods to contrast two potential explanations of impaired response inhibition during sleep deprivation. The first is a failure to stop: sleep deprivation reduces the ability to inhibit a response, reflected in lower efficiency of the stop process. The second is

a failure to start: sleep deprivation reduces the likelihood of initiating the stop process in response to the stop signal. 16 participants completed a stop-signal task in a control session and following 24 hours of complete sleep deprivation (counterbalanced). Sleep deprivation was associated with a failure to start: an increased probability of failing to trigger the stop process in response to the stop signal, and even an increased probability of failing to trigger the go process (i.e., response lapses). When the stop process was triggered, however, it was as efficient under sleep deprived and control conditions. These findings suggest that sleep deprivation might impair the ability to recognize environmental cues that indicate a response plan is inappropriate.

Revealing Neuro-Computational Mechanisms of Reinforcement Learning and Decision-Making with the hBayesDM Package

Ahn, Woo-Young, Haines, Nathaniel, and Zhang, Lei

Reinforcement learning and decision-making (RLDM) provide a quantitative framework, which allows us to specify normative and aberrant conditions with basic dimensions of neurocognitive functioning. Such a framework can also provide insights into the brain substrates of particular RLDM processes as exemplified by model-based functional magnetic resonance imaging (fMRI), wherein trial-by-trial latent variables are correlated against fMRI data. In addition, RLDM offer a novel approach to assess and potentially diagnose psychiatric patients. While there is growing enthusiasm on computational approaches among researchers in various areas, many of them often find the approach too technical and have difficulty adopting it for their research.

We introduce an R package called hBayesDM (hierarchical Bayesian modeling of Decision-Making tasks), which offers computational modeling on an array of RLDM tasks including Probabilistic Reversal Learning, Orthogonalized Go/NoGo, Two-Step, Two-Armed Bandit, Risk Aversion, and Delay Discounting tasks as well as social exchange games. The hBayesDM package offers hierarchical Bayesian modeling (using the Stan software package for Bayesian updating), where both individual and group parameters (i.e., posterior distributions) are estimated simultaneously in a mutually constraining fashion. At the same time, it is extremely user-friendly: users can perform computational modeling, output visualization, and Bayesian model comparisons–each with a single line of coding. Optionally, users can extract trial-by-trial latent variables (e.g., prediction errors and action values) that are required for model-based fMRI.

With the hBayesDM package, we anticipate that anyone with minimal knowledge of programming can take advantage of cutting-edge computational modeling approaches and investigate the underlying processes of and interactions between multiple decision-making (e.g., goal-directed, habitual, and Pavlovian) systems. We plan to add more tasks/models and also provide tutorials illustrating how other users can program their own models within our framework so that they can contribute to the hBayesDM package. In this way, it is our expectation that the hBayesDM package will contribute to the dissemination of advanced modeling approaches and enable more researchers to easily adopt computational tools for their research.

Sampling Distribution Characteristics of Common Connectivity Measures: A Simulation Study

Woodbury, George, and Thomas, Robin

Many statistical and signal processing measures have been applied to assessing connectivity/coupling between physiological signals in the time domain, as well as with a variety of other uses. However, the reactivity of many of these measures to signal and sampling characteristics is not well understood. A simulation study was conducted in order to approximate the sampling distributions of several real-valued connectivity measures used in EEG research. These real-valued connectivity measures were Average Mutual Information, Normalized Mutual Information, Cross Correlation, Phase Locking Value, and Magnitude Square Coherence. Simulated time series were generated using a high performance computing cluster, and the measures were repeatedly sampled across epoch, sampling rate, and model error variance conditions in order to attain approximate sampling distributions for all factor combinations. Key results were that several measures reacted radically differently across settings, with none reacting in the same way across the board. Recommendations for applying particular measures based on experimental constraints are thus implied.

Simultaneous Adaptation of Diffusion Model Drift and Threshold Parameters for Reward-Rate Optimization

Simen, Patrick, and Balci, Fuat

Using reward rate (RR) to investigate iterated, perceptual decision making has yielded interesting findings about when reward rate optimality (RRO) seems to occur, and when it doesn't. Ratcliff and colleagues have argued that RRO generally does not occur in humans; instead, participants care about, e.g., total reward in the available time, and they slow down rather than speed up when facing high difficulty, counter to RRO's prediction. Our own tests of the RRO hypothesis find that, in addition, participants usually appear to over-value accuracy at the expense of speed, disconfirming strong RRO. Nonetheless, when maximizing reward is the stated objective of a task and feedback is available, participants (young ones at least) can indeed achieve nearly optimal performance with practice, suggesting that humans are capable of responding exquisitely sensitively to reward rates. Interestingly, a common pattern in perceptual decision tasks is that accuracy is roughly constant throughout practice while speed increases – in our data, until RRO is reached. Thus RRO can explain the endpoint of learning processes (if not their trajectories during practice). A model of behavior that can explain these findings may be one that places a value on information requiring many trials to obtain. For example, dot-motion discrimination produces drift estimates that increase over multiple hour-long sessions, suggesting that the brain is slowly tuning its motion discrimination circuits to improve accuracy over many trials (contrary to the simplifying assumption of RRO that signal-to-noise ratio is fixed). To account for these patterns, we describe a diffusion decision model in which the drift and response threshold parameters are optimized simultaneously to maximize reward rate. The drift parameter adapts according to a hill-climbing process over an energy landscape representing the signal estimation error function over the

space of a neural network estimator's weights; the threshold parameter is just inversely proportional to reward rate. We analyze conditions under which this simple model predicts stable accuracy but increasing speed over practice, and we explore how the speed of drift-inflation during practice may be constrained by the jaggedness of the energy landscape.

Stochastic Modeling of Stress Effects on Rudimentary Information Processing

Neufeld, Richard W. James {Jim}, Grant, Bryan, and Shanahan, Matthew

Much information processing occurs in the company of psychological stress (e.g., physical danger, threat of extreme discomfort, social evaluation or failure threat). Such is the case in many occupational, educational, and military settings. Coping itself takes place under stress, and can be cognition intensive, as when making predictive judgments of threat. Despite considerable interest in stress effects, little mathematical research thereon has taken place. Candidate stress effects include reduction in speed of transacting constituent operations (subprocesses) of a cognitive process (e.g., rate of encoding items of a visual array); sub-optimal deployment of attentional resources to task elements; the impingement of intrusive associations; transition to a less efficient structure of processing (e.g., more serial, versus parallel, dispatch of task components); and curtailing of exhaustive, but necessary stimulus processing. The current focus is on possible change in processing structure, and speed of executing constituent task operations (element-wise cognitive-workload capacity). Participants psychometrically classified as more and less stress-susceptible (test anxious) reported as many letters as possible from a brief visual display (Sperling partial-report span of apprehension). A mixture model allowed for individual differences in tendered effects. Selective influence of stress-susceptibility on mixing-distribution hyper parameters was used to identify the more tenable structure as one of parallel treatment of display elements. Construct validity of parameter interpretation was achieved through analytic construct validity, a novel measure-theoretic method based on mathematical properties endowed by formal deductive systems in which the parameter tenably operates. Treating mixing distributions as Bayesian priors, it is shown that assessment precision of cognitive-workload capacity at the individual-participant level significantly exceeds that of maximum likelihood estimation, or one based on the prior itself. It is shown also that compromised cognitive-workload capacity at the display-element level, ramifies to substantial consequences at the full-display level, and to more complex tasks in which the latter participates. Within-trial dynamics of capacity consequences are model estimated.

Testing Contextuality in Cyclic Systems of High Ranks Using Psychophysical Data

Zhang, Ru, and Dzhafarov, Ehtibar N.

Contextuality-by-Default (CbD, [1]) is a mathematical framework for understanding the role of context in systems with deterministic inputs and random outputs. A necessary and sufficient condition for contextuality was derived for cyclic systems with binary outcomes [2]. In quantum physics, the cyclic

systems of ranks n= 5, 4, and 3 are known as systems of Klyachko-type, EPR-Bell-type, and Leggett-Garg-type, respectively. Physicists traditionally test contextuality by assuming consistent connectedness, meaning that the distribution of the outcome of a measurement is not directly affected by its context. According to CbD, quantum systems may be contextual even when consistent connectedness is breached, due to, e.g., context-dependent errors in measurements [2]. This is especially important in behavioral sciences, where consistent onnectedness (aka marginal selectivity) is almost never present. In earlier publications [3,4], we examined data collected in various behavioral scenarios, from polls of public opinion to visual illusions to conjoint choices to word combinations to our own experiments with psychophysical matching. No evidence of contextuality was found in these datasets. However, those studies were confined to cyclic systems of lower ranks (n=2,3,4). In this presentation, contextuality of higher ranks (n=6,8) was tested on our data with psychophysical matching, and again, no contextuality was found. This may indicate that all the seemingly contextual effects observed in behavioral sciences are merely violations of consistent connectedness (selectiveness of influences).

The Attention Weighted Sample Size Model of Visual Short-Term Memory: Signal Detection and Diffusion Model Analysis

Smith, Philip, Lilburn, Simon, Corbett, Simon, Sewell, David, and Kyllinsbaek, Soeren

We investigated the capacity of visual short-term memory (VSTM) in a phase discrimination task that required judgments about the configural relations between pairs of black and white features. Sewell et al. (2014) found that VSTM capacity in an orientation discrimination task was well described by a sample size model for both simultaneously and sequentially presented stimuli for displays of up to four items. The sample size model views VSTM as a resource comprised of a finite number of stimulus samples and predicts the invariance of the sum of squared detection sensitivities across items for displays of different sizes. For phase discrimination, the display size effect significantly exceeded that predicted by the sample size model for both simultaneous and sequential displays. With sequential presentation, the display size effect and the serial position curves were predicted by an attention weighted sample size model, which assumes that the first presented item captures attention and receives a disproportionate share of resources. The choice probabilities and response time distributions from the task were well described by a diffusion process model in which the drift rates embodied the assumptions of the attention weighted sample size model.

The Construct-Behavior Gap in Behavioral Decision Research: A Challenge beyond Replicability

Regenwetter, Michel, and Robinson, Maria

Behavioral decision research compares theoretical constructs such as preferences to behavior such as observed choices. Three common methods for connecting constructs to behavior are 1) to count the total number of choices of a certain kind across participants and decision problems, 2) to compare what most people choose in each decision problem against a predicted pairwise preference, or, 3) to

enumerate the decision problems in which two experimental conditions generate a one- sided significant difference in choice frequency. While simple, these methods are heuristics. They are subject to well-known reasoning fallacies, most notably the fallacy of sweeping generalization and the fallacy of composition. No amount of replication can alleviate these fallacies. The remedy to these very common problems lies in spelling out precise theories of how hypothetical constructs translate into behavior, not in successful replication of hard to interpret effects.

The Detrimental Effect of Recognition Memory Testing: Estimating Contributions from Item Interference, Context Change, and Response Bias and Boundaries

Osth, Adam Frederick, Jansson, Anna, Heathcote, Andrew, and Dennis, Simon

A robust finding in recognition memory is the observation that performance declines monotonically across test trials (Peixotto, 1947; Criss, Malmberg, & Shiffrin, 2011). Despite the prevalence of this result, there is a lack of consensus on the mechanism responsible for the decline. Three hypotheses have been put forward: 1.) interference is caused by the addition of test items into memory (Criss et al., 2011), 2.) the test items cause a shift in the context representation used to cue memory (Osth & Dennis, 2015) and 3.) participants change their bias and response caution through testing (Ratcliff, 1978). To investigate these hypotheses, we collected data from an experiment where list length and study-test delay were manipulated. The data demonstrated a decline in performance through testing in the long list conditions. We applied a global matching model to the data with a back-end diffusion process to allow for the model to account for both choice and response time simultaneously. The model allows for separate estimation of item interference (jointly constrained by list length and test position), the degree of match to the study context (jointly constrained by study-test delay and test position), along with response bias and boundaries.

The EZ Diffusion Model Provides a Powerful Test of Simple Empirical Effects

van Ravenzwaaij, Don, Donkin, Chris, and Vandekerckhove, Joachim

Over the last four decades, sequential accumulation models for choice response times have spread through cognitive psychology like wildfire. The most popular style of accumulator model is the diffusion model (Ratcliff, 1978), which has been shown to account for data from a wide range of paradigms, including perceptual discrimination, letter identification, lexical decision, recognition memory, and signal detection. Since its original inception, the model has become increasingly complex in order to account for subtle, but reliable, data patterns. The additional complexity of the diffusion model renders it a tool that is only for experts. In response, Wagenmakers, van der Maas, and Grasman (2007) proposed that researchers could use a more basic version of the diffusion model, the EZ diffusion. Here, we simulate experimental effects on data generated from the full diffusion model and compare the full

diffusion model and EZ diffusion on their power. We show that the EZ diffusion model, by virtue of its relative simplicity, is better able to detect experimental effects than the data–generating full diffusion model.

The Invariance Prototype and Information Prototype Models of Categorization

Vigo, Ronaldo

Prototype models of categorization (Estes, 1986, 1994; Nosofsky & Zaki, 2002; Reed, 1972; Rosch & Mervis, 1975; Smith & Minda,1998; Smith, Murray, & Minda, 1997) have been influential and some, such as the multiplicative prototype model (Nosofsky and Zaki, 2002), have been fairly effective at predicting a variety of categorization data. In this paper we show the limits of some of these classical models when used to predict the concept learning difficulty ordering of a large number of category structures such as the 76 studied by Feldman (2000) and the 84 studied by Vigo (2013). We propose that some of these limits stem from the fact that these prototype models are not sensitive to the contextual effects at play when learning novel concepts. We use Generalized Invariance Structure Theory (GIST; Vigo, 2013, 2014, 2015) and Generalized Representational Information Theory (GRIT; Vigo, 2011, 2012, 2013, 2014) as well as their core model of concept learning difficulty (the GISTM) to specify two new notions of prototypicality that purport to resolve this issue. The first of these notions, referred to as the “information prototype” (in the information prototype model), was first introduced in Vigo (2014). The notion, in addition to capturing contextual effects, transforms the GISTM into a process model capable of generating the probability of a correct classification for each member of a categorical stimulus, and shows how GIST can account for the origin of the prototype representation. The other, introduced here for the first time and referred to as the “invariance prototype” (in the invariance prototype model), also shows how GIST can account for the genesis of the prototype representation and how it can predict the probability of a correct classification for each member of a categorical stimulus -- however, it accomplishes this in a significantly different manner. Using the aforementioned datasets, performance of these two new models is compared to that of classical prototype models by Reed (1972), Estes (1986), and Nosofsky and Zaki (2002).

The List Strength Effect Won't Be Pushed Around

Wilson, Jack Harvey, Criss, Amy H, and Chen, Sharon

The list strength paradigm asks whether memory performance for a tested item is related to the strength of encoding of other items studied in the same list. We recently found a null list strength effect in cued recall. Within the REM framework, this suggests that the cue in cued recall is a weighted combination of item and context information. Our hypothesis is that placing more weight on context should induce a positive list strength effect whereas placing more weight on item information should induce a negative list strength effect. In In Experiment 1, we manipulate the relative contribution of item information to the recall process by strengthening only elements of the word pair. In Experiment 2,

we cued participants to rely more upon item information by providing additional item cues during recall. In Experiment 3, we cued participants to rely more upon context by increasing study-test lag. In all cases, we found null list strength effects regardless of manipulation. Implications for models of memory will be discussed.

The Pre-Computed Distributed Look-up Table Method for Real-Time Parameter Estimation

Fisher, Christopher R, Blaha, Leslie M, Walsh, Matthew M, Veksler, Bella Z, and Gunzelmann, Glenn

Even though computational models can be executed faster than real time, it is frequently the case that they take seconds to minutes to execute on traditional computing hardware. For model verification and validation, this can make parameter optimization time consuming. However, for real-time applications of computational models where parameters must be estimated, for instance for monitoring cognitive states, the time costs are typically prohibitively high. We present a method for estimating model parameters in real time, fast enough to run during task execution. The Pre-computed Distributed Look-up Table (PDLT) method utilizes the following steps. First, define the distribution over a plausible parameter space, based on parameters informed by theory and past empirical work. Then, simulate the model behaviors. Summarize those predictions with a statistic, such as quantiles or a kernel density function. The desired statistics are then stored in a look-up table. Once the look-up table is created, it can be searched for the parameters producing the best fitting behavior estimates to any given set of data. Best fit can be determined by maximum likelihood estimates. We demonstrate this technique through simulation of the psychomotor vigilance task. The speed of the PDLT is evaluated in terms of look-up table search times. The estimation accuracy of the PDLT is evaluated with a parameter recovery simulation. Parameter estimates from the PDLT are comparable to the estimates of a traditional simplex fit routine. The gain in speed can be attributed to two factors: (1) it eliminates redundant evaluation of the parameter space that is possible with simplex or gradient descent techniques, and (2) it separates the simulation time needed to generate the model predictions from the parameter estimation process. Thus, one benefit of removing simulation from the estimation process is the ability to scale the PDLT to complex models.

The Wisdom of the Crowd in Categorization Tasks

Danileiko, Irina, and Lee, Michael

The "wisdom of the crowd" is the idea that an aggregated group answer can be more accurate than any one person's answer. We apply this idea to category learning tasks, using the simple approach of combining people's categorization decisions by taking the majority vote for each stimulus. We show that this is an effective and accurate “wisdom of the crowd” measure that leads to quick category learning for seven previously reported experiments involving different sorts of stimuli. We then develop a model-based approach that can be used to generate group categorization predictions for new stimuli

that people have not seen. In order to do this, we first apply cognitive models to identify which categorization strategy each person in a task is using, and then use their model to predict a categorization response. The majority vote of these model-based predictions then becomes the group answer. To test this method, we look at an existing categorization data set with a large number of basic perceptual stimuli and apply a decision-bound model (GRT: Ashby & Townsend, 1986) to infer the decision boundary each person is using. We also look at an existing data set with more complex face stimuli and apply an exemplar model (GCM: Nosofsky, 1984) to infer the attention levels each person is using. In both cases, we show that the group decisions from our method for these new stimuli successfully predict the correct stimulus categorizations. We discuss how this approach can improve on machine learning methods, and be applied to more real-world data sets for more accurate group decisions.

Tree Inference: Reaction Time and Other Measures in Processing Trees

Schweickert, Richard, Han, Hye Joo, and Zheng, Xiaofang

Processing trees are often used in Cognitive Psychology to model response probabilities. A vertex represents a process and an arc descending from a vertex represents a possible outcome of the process. Each arc is associated with the probability the outcome it represents occurs. Occasionally each arc is associated with another measure, such as the time required for the outcome it represents to occur. But predictions are unwieldy unless a processing tree is relatively simple. We show that analysis is straightforward for experiments in which factors selectively influence vertices. An experimental factor selectively influences a vertex if changing the level of the factor changes parameters associated with arcs descending from the vertex, leaving all else invariant. Two processing trees are equivalent if they make the same predictions for response probabilities and response times for all combinations of levels of the two factors. Suppose two factors selectively influence two different vertices in an arbitrary processing tree. We show that the arbitrary processing tree is equivalent to one of two relatively simple processing trees. Parameter values are not unique. We characterize the possible values and derive expressions for degrees of freedom.

Two Categories for the Price of One: Generating a Contrast Category after Single-Category Learning

Conaway, Nolan, Austerweil, Joseph, and Kurtz, Kenneth

To study human category learning, researchers typically define a static set of categories and have participants learn them through an artificial classification task. In single-category designs, learners are typically exposed to members of a target class, and are then asked to indicate whether novel exemplars belong to the category. We discuss preliminary work on a novel paradigm where learners are sequentially presented with members of a single, experimenter-defined category, and are then informed of the presence of a second category. Learners then create exemplars belonging to this second category, using only their knowledge of the experimenter-defined class. The categories

generated by participants provide insight into the basis for classification when only a single category is known, as well as the role of contrast in conceptual representations. We discuss our results with respect to possible 'reference point' (e.g., prototype, exemplar) accounts of single-category generalization, as well as alternative accounts (e.g., Kurtz, 2007; Tenebaum & Griffiths, 2001).

Two Interpretations of Bayesian Statistics

Bamber, Donald

Two different interpretations of Bayesian statistics are described: the standard epistemic interpretation and an alternative simulational interpretation. In the epistemic interpretation, a model for a natural phenomenon is a description of one's beliefs about that phenomenon. In the simulational interpretation, a model is not a description of belief. Instead, a model for a natural phenomenon is a specification of probabilities for building an artificial stochastic device whose purpose is to mimic the behavior of the natural phenomenon. Under either interpretation, models are updated by conditioning on observations. Although the epistemic and simulational interpretations are radically different, every Bayesian statistical analysis can be subjected to either interpretation.

Understanding Automatic and Controlled Intertemporal Choice with a Two-Stage Sequential Sampling Model

Zhao, Joyce Wenjia, Bhatia, Sudeep, and Diederich, Adele

Dual process theories of decision making describe choice as the product of an automatic System 1, which is quick to activate but behaves impulsively, and a deliberative System 2, which is slower to activate but makes decisions in a rational and controlled manner. In this paper, we use this approach to analyze choice probabilities and response times (RTs) in intertemporal decisions. Consistent with the predictions of dual process theories, decision makers are quicker to choose immediate rewards compared to delayed rewards. On the individual level, the direction and magnitude of this tendency varies, but is correlated with standard measures of deliberative control, such as performance on the cognitive reflection task. We also fit our choice probabilities and RTs using a two-stage sequential sampling model, and find that this type of model is able to describe both aggregate and individual-level data. The best fitting model has a short stage 1 that appears to be insensitive to time delay, and a long stage 2 that takes into account both monetary payoffs and time delays.

Using Reaction Time Modeling of Forced-Choice and Same-Different Perceptual Decisions to Test a Race Model of Priming

Potter, Kevin, Donkin, Chris, and Huber, David

With immediate repetition priming of forced choice perceptual identification, short prime durations produce positive priming (i.e., higher accuracy when the target is primed, but lower accuracy when the foil is primed). In contrast, long prime durations reverse this pattern. The dynamic time course of this transition from positive to negative priming is well explained by the nROUSE model of Huber and O'Reilly (2003), which includes neural habituation. This model assumes that choices are made based on a race process and therefore it makes specific predictions regarding how rapidly the target and foil choices are identified. However, forced choice testing reflects a relative comparison rather than the absolute response to each alternative. To address this limitation, we collected both forced-choice and same-different responses in the same priming paradigm. We first addressed these data with a descriptive diffusion-race model (i.e., descriptive in the sense that the model made no a prior predictions regarding prime duration). We determined that the drift rate parameters implied by the single-item same-different task provided an adequate account of the relative comparison data from the forced-choice task. Furthermore, these drift rates were inversely proportional to the identification latencies of the nROUSE model even though the nROUSE and diffusion-race models were applied independently to the data. The consistency across tasks and across models lends support for the core assumptions made by the nROUSE model of perceptual priming.

Submitted Posters

Abrupt Strategy Shifts Underlie Gradual Performance Changes: Hierarchical Bayesian Models of Component and Composite Strategy Change

Wynton, Sarah Kate Ainsley, and Anglim, Jeromy

Research into how individuals acquire new skills has often examined changes in how they complete the task or changes in strategy use. This previous research has often utilized aggregated data to examine changes in single strategies on simple tasks. This study expands on previous research by examining models of individual level strategy use on a complex computer based task where changes in memory retrieval, information reduction, and insight, can be observed. Our aim was to examine whether these changes occur abruptly and, if so, whether these abrupt changes are smoothed over when different types of strategy change are aggregated into a global measure of strategy inefficiency. 163 participants completed 15 three-minute blocks of the Wynton Anglim Booking (WAB) Task. The task requires participants to make swimming class bookings by asking questions of the parent and selecting the right class on the timetable. Not asking irrelevant questions, retrieving class rules from memory and using filters to reduce the options shown on the timetable could reduce task completion time. Strategy use was measured as the proportion of trials a strategy was utilized within a block and aggregated measures

were calculated as the average of the components. We used Bayesian methods to fit abrupt and power functions to strategy use data within a hierarchical framework and evaluated them using deviance estimates, plots of model fits and posterior predictive checks. Plots of the data indicated that the component level strategies generally changed abruptly while the aggregated measures changed gradually. Although the power function was quite flexible and able to mimic the abrupt function, model evaluation generally supported the findings from the plots. While the results indicate that different processes may underlie the different types of strategy change, each showed abrupt changes at the component level and gradual changes at the aggregate level. We theorize that a possible reason we see gradual performance improvements resulting from abrupt changes in strategy use is because the abrupt changes occur at different points in practice for different types of strategy change.

A Hierarchical Diffusion Model Account of the Gaze Cueing Paradigm

Tanaka, Toshio, Okubo, Matia, Kunisato, Yoshihiko, and Okada, Kensuke

Human eye gaze pulls their attention to the direction they are looking at. Süßenbach & Schönbrodt (2014) used the gaze cueing paradigm to demonstrate that the perceived trustworthiness of a cueing person constitutes a moderator in this process. Procedure of this paradigm is as follows. First, the gaze cueing stimulus (trustworthy or untrustworthy face of a person) is presented. Then, the target stimulus is presented either to the right or left of the cueing stimulus. Participants answer the position of the target stimulus. In an additional exploratory analysis, they indicate potentially moderating influence of trait anxiety.

In the current study, the above results are re-analyzed by using the diffusion model in order to further examine the effect of trustworthiness and trait anxiety. The model assumes that the response process primary consists of four parameters, which are speed of information processing, accuracy, starting point, and encoding and response execution (Ratcliff, 1978). Moreover, some of the parameters are explained by the trustworthiness and trait anxiety. The results reveal the effects of them in the cognitive process of attentional shift.

A Horserace Model of Task-switching

Park, Joonsuk, Myung, Jay I., and Pitt, Mark A.

A new mathematical model of task-switching is proposed. Currently, to the best of the authors' knowledge, there does not exist an easy-to-interpret model of task-switching which is simple enough to be used as a cognitive psychometric measurement tool. Specifically, the new model, dubbed ‘HORTAS,' assumes that task-switching can be described as horserace process among different types of cognitive processes. Based on this assumption, the model is specified in each experimental condition, and the likelihood functions are derived in closed forms. It is shown that the new model predicts various well-known experimental effects and qualitative patterns of the data. In addition, some preliminary results are reported. The results suggest that task-switching ability can be reliably measured by using the new model, which demonstrates its practical utility in the applied and measurement-theoretic settings.

Analysis across Multi-Sensor Image Displays Using the Capacity Coefficient

Fox, Elizabeth L., Melas, Jordan, and Houpt, Joseph W.

Information from different parts of the electromagnetic spectral can yield unique benefits to aid in decision-making. Several sensor images can be presented to an observer simultaneously to potentially maximize the contribution of each image type. A recent article used the model-based measures of systems factorial technology to investigate how two methods of displaying multiple sensors simultaneously may differentially influence information processes. The display types included presenting the two sensors beside one another within 5 degrees of visual angle (cognitive fusion) or algorithmically combining the images into a composite image using a Laplacian Pyramid Transform. The authors found with simplistic imagery in two separate discrimination tasks both display types to have less efficient processes as more sensors were presented. Algorithmically combined image processing was even more inefficient than when the images were presented beside one another. Our study extends the previous research by 1) using more applied task asking participants to identify whether a suspect was holding a gun or a tool and 2) analyzing an additional display type: flickering the two sensor images back in forth at a rapid rate to obtain the benefits of both cognitive fusion (retaining all available information) and algorithmic fusion (confining the physical space for visual attention). All configurations were significantly less efficient than expected given performance with each sensor image alone. Despite the limited efficiency, presenting the images beside one another led to higher efficiency processing than both flickering the images and algorithmically combining the images. Although flickering the images back and forth intuitively combines the benefits of the alternative methods previously investigated, the presentation of the two images beside one another may have an additional benefit that is absent in the flicker condition: performance gains from redundant information across the two images. Future research should look to explore how to maximize the potential benefits of redundancy with multi-sensor imagery.

Bayesian Excursions in Decisional Control: A Hierarchical Decision-Making Mixture Model

Shanahan, Matthew J., Grant, Bryan, and Neufeld, Richard W.J. {Jim}

In our mixture model of decisional control, allotment of probability for target outcomes in hierarchical decision-making (schematized as bin-sets, bins nested therein, and elements nested in bins) is regimented by a complete set of closed-form solutions. Assumptions include: maximax decision-making, random allotment when choice is absent, ordinal ranking of threat of occurrence across all hierarchical end-points, and equal number of options among level-wise subsets (i.e., among bins, among elements).

Occurrence of a qualitatively observable event is the basis of the behavioral sciences. In managing prediction and expectation of desired or undesirable events, hierarchical modeling can yield more or less efficient and more or less leveraged sets of expectations. In managing stress and threat in clinical situations, a theoretical basis for expectation of relapse, panic attacks, or other undesirable clinical events can be found by using formally-modelled hierarchical concatenation of probabilities. These hierarchies systematically allot event likelihood based on availability of choice, of information, or lack

thereof. The layers of this mixture model bespeak a root system: the emergence of a new, desired 'shoot' (clinically-desirable behaviour), or a 'weed' (undesirable clinical event) can be quantitatively expected across a panoply of different scenarios.

The nesting layers of parameter distributions, in increasing order of palpability, are: a) the distribution of decision-structure constituents (Choice, C; No-Choice, N; Uncertainty, U) given decision features in the environment, b) decision structures (CC, CN, CU, …, UU) given decision-structure constituents, c) likelihood Pr(t[i]) of obtaining an optimal threat value, t[min] , in specific (indexed) ordinal position i, given a decision structure, d) threat value t for event occurrence given likelihood of obtaining ordinal position i for Pr(t[i]), and e) event occurrence or non-occurrence m (m = 1 or 0, respectively) given threat value t.

The ability to lay hold of 'one feature of the elephant' in a way that is yoked to a comprehensive arrangement of nested and nesting parameter distributions ('the whole elephant') allows the specification of expectations for any portion of this mixture model by a subset of contextualized parameter values. This can facilitate specification of research hypotheses, and the identification of parameter settings amenable to programmatic research.

Bayesian Multidimensional Item Response Models for Measuring Response Styles Using Anchoring Vignettes

Hojo, Daiki, and Okada, Kensuke

In questionnaire surveys, it is reasonable to expect that respondents' observed scores reflect not only their traits to be measured but also their response styles. For example, a respondent who demonstrates the Extreme Response Style (ERS) tends to select endpoints categories in rating scales such as "strongly agree." On the other hand, a respondent who demonstrates the Midpoint Response Style (MRS) tends to select intermediate categories such as "neither agree nor disagree." Although many studies ignore the effect associated with response styles, it is important for us to explicitly address this problem in order to avoid biased results. Hence, Bolt et al. (2014) proposed, using Bayesian framework, a Multidimensional Item Response Theory model which measure and control for the effect of response style. They compared the following three models using data on conscientiousness: [Model 1] no response style, [Model 2] only ERS and MRS, and [Model 3] free-parameter response style. They indicated that the Model 3 is the best in terms of DIC. Still, it is not known whether this tendency also generalizes to other dataset or not. Therefore, we analyze sleep data from the World Health Survey (2002) using the same models. Moreover, we conduct predictive model comparison using improved information criteria such as WAIC and LOO. The usefulness of anchoring vignettes model in psychology is discussed.

Bayesian Ordinal Analysis: Applications of the Polychoric Correlation Coefficient in Psychology

van Doorn, Johnny, Marsman, Maarten, and Wagenmakers, Eric-Jan

An often recurring question in psychological and cognitive science is whether its constructs ought to be treated on the ordinal level, or ratio/interval level. Examples of such data are Likert scales, preference rankings, or test performance scores. Having statistical analyses closely related to the measurement level of the data diminishes the risk of erroneous assumptions and better approximates the psychological processes underlying the observed data. In viewing data as the ordinal manifestation of a latent, normally distributed variable, the actual construct that psychologists strive to measure is more accurately quantified in terms of uncertainty. A crucial example in this context is the measurement of IQ, a variable that is often treated on the interval or ratio level, thus disregarding that IQ scores are merely a measure of the latent trait of intelligence. The current project introduces this latent level (i.e., data augmentation) for Bayesian correlational analysis in a bivariate setting. By using a Gibbs sampling algorithm, it is possible to obtain the joint posterior distribution for the latent values and Pearson's correlation coefficient between two variables based on the ordinal level: the polychoric correlation coefficient. In doing so, the uncertainty of psychological measurement is accounted for by the width of the posterior distribution. Furthermore, a Bayes factor can be obtained, allowing Bayesian hypothesis testing of the nullity of a correlation.

Characterizing the Relationship Between Semantically Similar and Unrelated Items in Recognition Memory

Curl, Ryan A, and White, Corey N

A number of different factors influence performance in recognition memory tasks. The present work investigates how item similarity affects the dynamics of recognition-based decision making. Previous research has shown that studying similar, categorized items results in a bias in which words related to the test words are more likely than neutral words to be labeled as studied or “old”. My program of research is designed to explore the relationship between the categorical “old” bias and memory for neutral words. Analyses of hits and false alarms reveal two factors that result in the categorical “old” bias: an increase in memory strength for categorized items and the adoption of a conservative criterion when strongly familiar items are expected on the test. Thus the categorical nature of stimuli in the recognition task affects memory and decision processes.

We incorporated response time analyses to better understand the effects of item similarity in recognition memory. The results show that participants are slower to correctly reject unstudied categorical words compared to unstudied neutral words. This effect seems to be dependent on the strength of the categorical “old” bias, where greater categorical “old” biases lead to longer response times when correctly identifying unstudied categorized words. False alarms for categorical stimuli seem to happen early in the decision making process, whereas correct rejections happen later. But this RT pattern is not seen with neutral words.

I describe these results in terms of the Drift Diffusion Model (DDM) framework. The conventional DDM assumes that evidence for a decision (drift rate) accumulates at a constant rate throughout the decision

making process. The RT effects with categorized words appear inconsistent with the standard assumption of a constant drift rate, namely because the false alarms occur much earlier than correction rejections for categorized words only. This might be indicative of a drift rate that varies throughout the decision making process, driven by category information becoming available before item-specific information. I plan to characterize these effects in terms of accuracy and response times to create a foundation for testing assumptions about how category and item information interact to produce a time-varying drift rate in the DDM. The resulting model will combine memorial and decision processes to better account for the effects of semantic similarity in recognition memory.

Deep Learning and Attentional Bias in Human Category Learning

Caglar, Leyla Roksan, and Hanson, Stephen Jose

Human category learning is known to be a function of both the complexity of the category rule and attentional bias (Shepard, Hovland, & Jenkins, 1961; Smith & Medin, 1981). A classic and critically diagnostic human category problem involves learning integral stimuli (correlated features) using a condensation rule and separable stimuli (independent features) using a filtration rule (Garner, 1974). Human category learning shows differential learning speed based on category rules that either require attentional binding or ignoring features. A plethora of work has shown that standard backpropagation neural networks (BP) with one sigmoidal hidden layer require some built in pre-designed perceptual bias (e.g. localized kernels, feature competition) to learn or distribute attention. However recent advances in neural network theory show benchmark results with multi-hidden-layer Deep Learning networks (DL). One hypothesis concerning the nature of representations through successive re-encoding in DL is that the sequential extraction of features encourages the development of more sensitive feature detectors that can regularize for both the complexity of the stimulus and the category rule. In this paper we show that DL learns both the category rules while modeling the attentional bias consistent with the human performance in a task of categorizing realistic 3D-modeled faces. Two distinct prototypes generated 120 faces manipulated on two dimensions: genetic-relatedness and emotion (neutral, happy, very happy). To create appropriate integral/separable stimuli, we selected appropriate features from multidimensional scaling the stimuli in 5 dimensions (accounting for > 90% of variance in behavioral similarity judgments (N=20) and calculated the correlation between faces to identify two clusters of high and low correlations. A 2x2 design for separable/integral and filtration/condensation was used to obtain behavioral data (N=80) as well as to test the BP and the DL. Similar to past results, participants were faster and showed less variance with learning the filtration/separable condition than with learning the condensation/integral tasks. As predicted the representations visible in the hidden layers of the DL, but not of the BP, show perceptual biases congruent with the appropriate type of stimulus and the amount of covariation in the stimulus features, leading to successful modeling of human-like category learning.

Disentangling the Testing Effect

Lew, Timothy Franklin, Tran, Randy, Pashler, Harold, and Vul, Edward

Research has suggested retrieving material improves memory more than simply restudying. However, it is unknown how this “testing effect” changes the content of memories in a way that facilitates recall. Retrieval practice may help memory by reducing imprecision, decreasing misassociations, or preventing

the spontaneous loss of those memories. Here we use a Bayesian mixture model (see Lew, Pashler & Vul, 2015) to disentangle these possible sources of forgetting and ascertain how the testing effect improves memory.

We trained subjects on the locations of 12 objects and later asked them to recall the locations. Subjects first studied the true locations in four cycles of passive presentation. Afterwards, subjects reviewed the objects four times by 1) observing them in their correct locations, 2) recalling their locations or 3) recalling their locations and then receiving feedback (seeing the objects in their correct locations) (within subjects). Subjects returned after either 2 days or 1 week (across subjects) and recalled the objects' locations.

Retrieval practice with feedback resulted in the best performance. Root mean square error was lowest for the feedback condition after 2 days and even more so after 1 week. We first examined how feedback helped retrieval practice. After 2 days, practice without feedback caused subjects' responses to drift away from the correct locations and closer to their previous responses. After 1 week, previous responses no longer biased new responses, presumably because subjects forgot their previous responses.

We next used a mixture model to estimate how much errors were due to imprecise memories, misassociations and random guessing (spontaneous memory loss). Noise increased over time, and restudy and feedback resulted in memories with comparable precision. Consistent with the patterns of drift, without feedback locations were initially exceptionally noisy but resembled the other conditions after 1 week. Although subjects at first accurately retrieved memories in all conditions, after 1 week the probability of misassociations increased in restudy and no feedback. We observed few random guesses.

Our results suggest that retrieval practice without feedback can cause memories to drift while restudying allows people to form precise memories that are confused with each other. Retrieval practice with feedback is most effective because it allows people to both retain precise memories and maintain associations between those memories.

Does Prior Knowledge Influence the Fragility of Associations in Memory

Persaud, Kimele, Hemmer, Pernille, and Ahluwalia, Daljit

An important question of long-term memory is what happens to the memory trace over time. On the one hand, previous research suggests that although memory traces can be quickly formed and retained for a long time, memory associations are slowly formed and are quickly forgotten (Lew, Pashler, & Vul, 2015). In contrast, other work suggests that prior meaningful associative information in the stimulus environment influences recall of current episodic events and improves average accuracy (Hemmer & Steyvers, 2009a; Hemmer, Persaud, Venaglia, & DeAngelis, 2014). These contradictory findings can be reconciled by understanding the nature of the associative information. While arbitrary associations (e.g. the location of objects or color squares in a circle) are fragile in nature, and account for the difficulty in forming and retaining information, we hypothesize that meaningful associations will produce an opposite effect. Once formed, these associations will be less fragile and can be sustained over time. Here, we present the findings from a series of experiments assessing memory for associations that vary in degree of meaningfulness. Models of long-term memory that support both accounts are discussed.

Effect of Reward Structure on Learned Attention to Cues

Paskewitz, Samuel Peter, and Jones, Matt

It is well known that people learn to attend to cues in proportion to how well they predict discrete outcomes, such as category labels, a result reproduced by many mathematical models. However, there has been less research on the more complex question of how attention is learned in tasks involving continuous outcomes, such as rewards. Recently, Le Pelley, Mitchell and Johnson (2013, J Exp Psychol Anim Behav Processes) have shown that cues predicting larger rewards receive more attention. However, this result could also be explained as attention being drawn to cues that signal a greater difference between the rewards following different actions, and hence greater importance of the participant's choice. We have identified these and other functions of task reward structure as candidate factors driving attention, and used this analysis to generate experimental designs that can dissociate their effects. We derive predictions from existing mathematical learning models for these designs. Also, we report preliminary results of an experiment designed to dissociate the effects of average reward and choice importance.

Estimating the Capacity of Memory Across Eye-Movements Using Ideal Observer Analysis and Rate-Distortion Theory

Kleene, Nicholas, and Michel, Melchi

Our primary means of gathering information about the world is through vision. Each fixation provides us with a sample of the visual world; however high fidelity information is only present at the fovea. Since visual acuity is limited in the periphery, integrating visual samples across fixations becomes critical in guiding subsequent eye-movements. Each sample must be stored in memory so that it can be integrated with the current fixation, which makes transsaccadic memory (TSM) a necessary part of this integration process, particularly in visual search tasks involving multiple fixations. In the current study, we conducted two visual search experiments to estimate the capacity of TSM: one where participants made real saccades, and one where participants maintained fixation while we simulated a saccadic transient. Both tasks required participants to locate a target signal (Gabor) in a field of 1/f filtered noise. Participants were presented with one, two or four samples of the stimulus, with the target either present in every interval or just one. In the real saccade experiment participants made 5° saccades following each sample of the stimulus, while in the simulated saccade task observers maintained fixation as we presented the simulated transient. Performance was measured as target localization accuracy. We then fit an ideal observer model to each participant’s sensitivity and estimated memory encoding noise using rate-distortion theory. We found significantly higher capacity estimates in the real saccade task than in the simulated saccade task, indicating that visual memory may be optimized for tasks requiring eye-movements. We also tested two plausible memory encoding strategies, one where TSM capacity is split evenly among individual samples and target locations, and one where TSM capacity is allocated according to the posterior probability at each potential target location. We found that allocating TSM capacity according to the posterior significantly improved performance for simulated observers with small TSM capacity relative to task demands, and that these observers required greater weighting of the posterior to achieve optimal performance. We conclude that as task demands on TSM rise, this posterior-weighted dynamic allocation of TSM capacity becomes increasingly beneficial.

Extending Temporal Context Models to Perceptual Representation

Cruzado, Nathanael A., DiLascio, Joe, and Howard, Marc W.

In temporal context models, a gradually changing representation of the recent past is used to bridge across time, allowing for an account of canonical memory effects such as recency and contiguity. Many computational models of semantic memory exploit regularities in temporal co-occurrence of words in natural corpora of text to construct representations of word meaning. Temporal continuity may also be an important cue in constructing spatially invariant object representations in vision. The visual input to the retina contains temporally structured input over a range of time scales. To take a simple example, an object in the world activates an entirely different set of sensory receptors when its image lands on the fovea as compared to when the image lands in the periphery of the retina. However, saccadic eye movements make these two retinal images contiguous in time. If the visual system could exploit temporal relationships, this could be a mechanism for spatially invariant representations. Similarly, saccades between objects could allow the visual system to learn consistent spatial and temporal relationships between naturally occurring objects in much the same way that semantic relationships between words are developed in semantic memory models.

We extend the predictive temporal context model (pTCM), developed to describe semantic memory to describe canonical effects in visual neurophysiology experiments. We first extend the model by using a scale-invariant generalization of temporal context, enabling in principle a much richer account of semantic memory. We then fit neural activity from several vision experiments to operators in pTCM. The scale-invariant representation of temporal context enables a description of results from the monkey cortex at the time scale of saccades up to the scale of tens of seconds. In principle, the scale invariance of the representation allows a description of much longer time scales as well. We discuss how to generalize this approach to accommodate both temporal and spatial relationships.

Eye Movements during the Integration of Information across Graph and Text in a Decision-Making Task

Rubinstein, Jason F., Aitkin, Cordelia D., and Kowler, Eileen

Gathering and integrating information from spatially distinct and qualitatively different sources requires decisions about when and where to sample information. An example is reading graphs and accompanying text to arrive at a coherent interpretation. Eye movements were recorded while Ss viewed bar graphs depicting information about two attributes of two fictitious products, along with descriptive text, and asked to indicate product preference. Perceptual-motor configurations were: (1) Simultaneous: Graph and text adjacent, requiring a saccade to switch between them; (2) Eye contingent: Graph and text sequential, with each triggered by a saccade, and (3) Button-press: graph and text sequential, with each triggered by a button press. Text was either redundant with the graph, or contained different information. Attributes were either consistently better for one of the products or inconsistent. Ss typically read the entire text early in the trial before switching to the graph. Eye movements while reading the graph showed frequent revisits of key features (legend; axes) similar to the memory-driven re-visits modeled by Epelboim & Suppes (2001) for geometry problems. Total viewing time was about equal for all perceptual-motor configurations, but viewing strategies were very different: Visits to graph or text were shortest in the Simultaneous condition (5.4s), with more

transitions between graph and text (.15 transitions/s), than in either Eye-contingent (9.8s; .074 transitions/s) or Button-press (10.5 s; .055 transitions/s) conditions. The effect of perceptual-motor configuration was surprising given how little effort was needed to switch between graph and text. In the Simultaneous condition graph viewing time was reduced by half when text and graph were redundant or when product attributes were consistent. Overall, strategies were characterized by (1) preferences to integrate graph and text at a high level, rather than feature-by-feature; (2) avoidance of even modest increases in motor effort to switch between graph and text; (3) preferences to avoid the graph in easier conditions (redundant content; consistent product attributes). Strategies of integrating graph and text may be similar to what has been found in other problem-solving or search tasks, namely, moment-by-moment preferences to avoid allocating cognitive resources or expending perceptual-motor effort on anything but the most essential elements of a task.

Letter Spacing and Target Uncertainty Effects on Word Identification Capacity

Zhang, Hanshu, Melas, Jordan, and Houpt, Joseph

Houpt, Townsend and Donkin (2014) reported that using capacity coefficient as a powerful tool in assessing word processing efficiency. The capacity coefficient measures the change in efficiency of letter identification as a function of whether they are in a word context or alone. In the first experiment of our current study, we replicated Houpt, Townsend, and Donkin's finding of a word superiority effect using varying target words across trials instead of a fix target word. The target words were all four letters (e.g. "golf", "pile", "runt", etc.) and were chosen such that any letter within the word could be swapped with at least one other letter to create a distractor word. For example, "pile" can turn into "file" by replacing "p " with "f ". Similar to Houpt, Townsend and Donkin, we found high levels of super capacity for words. In the second experiment, we measured the effect of letter spacing on word processing efficiency with varying target words. Regardless of intra-letter spacing, we found word superiority. Wide intra-letter spacing (twice as wide as normal spacing) led to reduced super-capacity, but we did not find evidence of an affect when intra-letter spacing was narrowed (80% of normal) relative to standard spacing. In future work, we hope to replicate earlier findings that word superiority effects are nullified when the intra-letter spacing is irregular (cf., Purcell & Stanovich,1982 ; Marchetti & Mewhort, 1986) using this design.

Mixing Risk With Time

Wall, Daniel Gregory, Hemmer, Pernille, Chapman, Gretchen, and Pei, Kevin

Understanding the combination of risk and time preferences is not as simple as merging a model for risk preferences with a model for time preferences (Andreoni & Sprenger, 2012; Hardisty & Pfeffer, 2015). Andreoni and Sprenger (2012) and Hardisty and Pfeffer (2015) both show that a combination of prospect theory and temporal discounting models cannot account for risky intertemporal choices. These results call into question the current unified theories of risk and temporal preferences (e.g. Loewenstein & Prelec, 1992; Rachlin & Raineri, 1992). Furthermore, there has been a recent advances cognitive models to explain riskless intertemporal choices (e.g. Dai & Busemeyer, 2014; Read, Scholten, Sanborn, 2014; Scholten & Read, 2010). We aim to use these recent advances to explore a model which combines both risk and time. Although Hardisty and Pfeffer (2015) show that both amount and outcome risk alter intertemporal choices, they do not show how the combination of amount and outcome risk alter

intertemporal choices. Amount risk means that the amount paid is pulled from a random distribution (e.g. a random amount between $50 and $150), while outcome risk means whether or not you are paid is pulled from a random distribution (e.g. a 50% chance of receiving $200). The combination of amount and outcome risk is operationalized via a roulette wheel with differing amounts on it (e.g. $220, $180, $0, $0). We propose that the combination of amount and outcome risk on intertemporal choices will not differ from outcome risk alone because once there is outcome risk, amount risk does not matter. This is conceptually similar to a diminishing sensitivity to risk. The ultimate goal is to present a Bayesian model of risky intertemporal choices. Understanding the cognitive processes that underlie risky intertemporal choices has wide-reaching practical implications for investors and consumers.

Modeling Active Learning: Roles of Distributional Information in Decisions to Explore

Lapidow, Elizabeth, and Bonawitz, Elizabeth

Everyday decision-making is filled with choices about what to act on, with outcomes playing a critical role in learning. Information gain is oft cited as a valuable approach to maximize potential learning, but its computation is costly. It entails evaluating the probability of multiple outcomes given any possible action, and then considering the degree of belief-change over all possibilities. Given the computational complexity of this evaluation, it becomes important to ask whether learners employ other cues as heuristics that drive choice. We present several models of choice behavior in a learning context, comparing a model of information gain to a variance-only model. We also explore two heuristics (distributional N and category variance) as possible influences on adult's choices. Models are compared to human behavior in a set of experiments which ask participants to choose between two options (varying in distributional characteristics) in either a “learning-condition” or “collecting-condition”. Our results show that individuals are sensitive to cues, but only favor them in learning-goal contexts, suggesting an important context-specificity for future computational models of decision making.

On the Shape of Memory-Strength Distributions in Individual ROC Data

Malejka, Simone, and Bröder, Arndt

The question of whether performance in recognition-memory tasks should be measured assuming continuous memory strength or discrete memory states has a long tradition in memory research. Continuous-strength models (i.e., signal-detection theory) propose that memory strength varies according to Gaussian distributions, leading to graded memory-strength values. In contrast, discrete-state models (i.e., threshold theory) assume a finite set of memory states and are mathematically equivalent to models with rectangular distributions of memory strength. Although the models’ core properties and their associated psychological interpretations differ, the form of empirical receiver-operating characteristics (ROCs) supports neither of the rival models absolutely and the models’ fits to empirical ROC data are usually highly correlated. In a series of reanalyses and new experiments, we explore the shape of the memory-strength distributions on aggregated and individual level using a signal-detection model with Tukey-lambda distributions. This family of distributions contains Gaussian and rectangular distributions as special cases, expressed by a single shape parameter. The results show that empirical memory-strength distributions have a hybrid shape that is neither completely Gaussian

nor completely rectangular. Hybrid shapes argue (a) for memory strength that is sometimes graded and sometimes thresholded (e.g., dual-process theory) or (b) for memory strength that is never completely graded or thresholded (e.g., fuzzy thresholds).

Optimal Predictions in Illness Cognition

Robbins, Talia, Hemmer, Pernille, Leyble, Kaitlin, and Spencer, Chrystal

People make accurate predictions for many real world events e.g. human life spans (Griffiths & Tenenbaum, 2006). Accurate predictions are particularly important in the domain of health, where illness knowledge directly influences patient outcomes. To understand how well peoples' illness expectations were aligned, we asked participants to estimate durations for 9 illnesses, and compared their responses to the real-world distributions. We found that for common acute illnesses (e.g., the cold) people make accurate predictions, whereas for rare chronic illnesses (e.g., COPD) people make comparatively poor predictions. Further, we found that participants overestimate the prevalence of every illness, especially for those that are more common (e.g., the cold). Taken together, these results suggest that people more accurately estimate the duration of common acute illnesses, but this may cause them to overestimate the prevalence of these illnesses. Results will be discussed in terms of implications for both cognition and behavioral health theory.

Position Uncertainty, Clutter, and Performance in Naturalistic Search Tasks

Semizer, Yelda, and Michel, Melchi M

Studies of visual detection and discrimination have consistently demonstrated that uncertainty about the position of a stimulus impairs performance. Importantly, the source of this position uncertainty can be either extrinsic (EPU), or intrinsic (IPU) to the observer. Most studies investigating position uncertainty have focused on the effects of EPU. However, we recently measured IPU in human observers and showed that it can account for systematic drops in detection and localization performance in the visual periphery. In the current study, we sought to measure the effect of IPU in more naturalistic search tasks involving a sequence of gaze changes.

In one set of experiments, we used a detection task to measure human observers' visual sensitivity to the target signal as a function of visual field position. Then, observers completed an overt search task in which a target signal was embedded in a noisy background. We manipulated two features of the search task: the distribution of "feature clutter", which could be uniformly or sparsely distributed, and the set size, or number of potential target locations. The clutter manipulation was designed to modulate the effect of IPU, which is enhanced when clutter is uniformly distributed and attenuated when it is sparsely distributed.

We developed an ideal searcher model that was limited by the IPU measured for human observers. Introducing IPU to the ideal searcher impaired its overt search performance, but not uniformly. When feature clutter was sparsely distributed, performance decreased steeply as a function of increasing set size. When feature clutter was uniformly distributed, the effect of IPU dominated and performance

flattened as a function of set size. Measured performance for human searchers showed similar trends. The results suggest that IPU limits search performance even when observers are allowed to make eye movements.

In a second set of experiments, we are examining the effect of IPU as a function of visual clutter in natural images. The search task requires localizing objects (e.g., cell phones, keys, etc.) in the contents of bags. We measure the amount of clutter within each image and use only a subset of high and low cluttered images in the task. We also manipulate the set size, or number of potential target locations. The results of this follow-up experiment will show whether we can generalize our previous findings to real life search scenarios.

Sensitivity to Shape Differences Along Morph-Spaces

Destler, Nathan, Singh, Manish, and Feldman, Jacob

MOTIVATION. We investigated the dimensions defining mental shape space, by measuring shape discrimination thresholds along "morph-spaces" defined by pairs of shapes. Given any two shapes, one can construct a morph-space by taking weighted averages of their boundary vertices (after normalization), creating a continuum of shapes ranging from the first shape to the second. Previous studies of morphs between highly familiar shape categories (e.g. truck and turkey) have shown elevated discrimination at the category boundary, reflecting a kind of "categorical perception" in shape space. Here, we use this technique to explore implicit categorical boundaries in spaces of unfamiliar shapes, where categories are defined not by familiar named types, but by the underlying "generative" structure of mental shape space. We further explore how probabilistic skeletal models of shape may explain discrimination and categorization of these unfamiliar shapes. METHODS. Subjects were shown two shapes at nearby points along a morph-space, and asked to judge whether they were the same or different, with an adaptive procedure used to estimate discrimination thresholds at each point along the morph-space. We targeted several potentially important categorical distinctions, such one- vs. two-part shapes, two- vs. three-part shapes, changes in symmetry structure, and other "qualitative" distinctions. RESULTS. The results show strong consistency between subjects. Sensitivity (1/difference threshold) is predicted by computing the probability of the standard shape being generated by the comparison shape’s generative model. CONCLUSION. The results show that discrimination thresholds are not uniform over shape spaces. Instead, the a probabilistic generative framework appears to drive shape discrimination.

Separating the Effects of Practice and Age-Related Change in a Longitudinal Study Design

Broitman, Adam Wood, Healey, M. Karl, and Kahana, Michael J.

Designing interventions to remediate age-related memory decline is a key challenge facing cognitive science. Detecting the effects of these interventions requires precise measurements of how memory performance changes across time in longitudinal studies. Obtaining such precise measurements requires participants to complete many trials, however this introduces the possibility of practice effects, which

can mask age-related changes. We developed a simple mathematical model, $P_{recall}=\beta_0-\beta_1 Age+(\beta_{prac}-\beta_{prac} / \sum_{i=1}^{n} t_i^{-d})$, based on the strength accumulation equation (Anderson, Fincham, & Douglass, 1999, JEP:LMC) in which probability of recall is a function both of linear effects of age-related memory change as well as power law effects of practice. Previous work suggests that in a free recall paradigm, the percentage of words successfully recalled can be expected to decrease by 0.4 each year. A Monte Carlo study was used to assess the ability of the model to detect this modest age-related change. We then applied the model to data from a 4-year longitudinal study of free recall in adults over 60. Participants in this study showed no evidence of age-related decline when a basic linear model was fit to their recall data. However, the application of our model revealed the presence of a significant age-related decline that was being masked by practice effects.

Skill, Knowledge, and Predictability in Majority Decisions

Lee, Michael David, and Lee, Megan Nicole

If an 80% majority of a crowd of people think a roulette spin will turn out to be red, they are right about half the time. If the same 80% majority think one line is longer than another in a psychophysical task, however, they are almost certainly right. Between these extremes lie general knowledge domains for which people have some distribution of expertise, and prediction domains for which people have some distribution of skill. For these domains, larger majorities generally signal greater accuracy, and the relationship between the size of the majority and the level of accuracy reveals something about individual differences in knowledge and the predictability of the domain. We study empirically the relationship between the size of the majority and its accuracy in a variety of domains, including gambling, ESP, psychophysics, general knowledge of city populations, company values, actor and athlete salaries, and predictions about sport, fantasy sport, and electronic sport outcomes. We then develop models for the crowd behavior that depend on the distribution of knowledge and skill of people, and the inherent predictability of a domain, and apply them to our data. The ability of our approach to measure the balance between skill and chance in a domain, and its potential applications, are discussed.

Testing Reinforcement Learning Models for the Iowa Gambling Task

Haines, Nathaniel, and Ahn, Woo-Young

Intro:
The Iowa Gambling task (IGT) has been widely used for studying decision-making in healthy individuals and clinical populations. Reinforcement learning (RL) models can be used to break down choice behavior on the IGT into several processes. Various models have been proposed (e.g., Expectancy Valence Learning, Prospect Valence, Learning, Value-Plus-Perseverance) but so far no single model outperformed competing models in all model comparison indices including goodness of fit, simulation performance, and parameter recovery. The goal of the current study is to identify a RL model that would show excellent performance in all indices.
Methods:
We examined several new models based on existing literature in psychology and neuroscience. For preliminary data analysis, we used hierarchical Bayesian parameter estimation using the Stan software

package and tested model goodness of fit with Watanabe-Akaike Information Criterion (WAIC) and Leave-One-Out Information Criterion (LOOIC). We compared the candidate models with existing models.
Results:
Preliminary results suggest that a combination of a learning model that accounts for reversal learning and also allows for variable learning rate over trials (Binary Fictitious Choice model) outperforms one of the existing models (Prospect Valence Learning model with the delta rule).
Discussion:
Future research should focus on exploring extensions to the current Binary Fictitious Choice model, as well as looking at other model comparison techniques such as simulation performance and parameter recovery.

The Leadership Resources of Managers: from Testing to Mathematical Modeling

Gryazeva-Dobshinskaya, Vera, and Dmitrieva, Yulia

The manager's activity – condition of successful introduction of innovations is revealed itself in peculiar features of motivation, creativity, leadership. The activity resources are considered in a ratio of tendencies: innovative (aimed at the search, change and transformation) and stabilizing (aimed at the maintenance of usual functioning).

120 managers of the enterprises took part in the research study in order to detect a group with the maximum level of innovative activity. The empirical study involved the testing of the leadership with the help of B. Bass and B. Avolio's MLQ technique. The differentiation of managers on the basis of the ratio of indicators of MLQ maximizes the group of managers with average indicators of the leadership styles, and the group of managers with high and low indicators as a result of psychometrics of the technique is minimized. Additional resources of the innovative activity of entities might be connected with correlation of indicators of the leadership structure. The mathematical modeling method is developed for determination of the effect of indicators.

For mathematical modeling of the activity resources the system of two equations, which takes into account a type of indicators interaction ("cooperation", "competition", "predator-pray", "neutralism") was applied. As a result of approbation of the method it's found out that an optimal model of indicators interaction is a "cooperation" model, where indicators of the innovative activity are maximal. Integral indicators are calculated by the method of mathematical modeling of leadership resources. The empirical values of the integral indicators were standardized. The mathematical modeling of the activity resources was conducted individually for each manager. Coefficients in the equations are equal to various MLQ indices. The solution of the equation system specifies an "equilibrium point" which in the Cartesian coordinate system represents a cross point of the innovative and stabilizing tendencies of the activity. The coordinates Y and X are stationary solutions of the equations, they are values of parameters according to each tendency of the activity.

The method of mathematical modeling of the activity resources restructures groups of managers differentiated by the results of testing, which reveals itself in reduction of a number of managers with average resources of the innovative activity and increase in a number of managers with high and low resources of the activity.

Understanding Effects of Emotion on Memory Bias and Discriminability as a Function of Output Interference

Sloane, Jennifer, and White, Corey

This experiment was conducted to understand the effects of emotion on memory bias and discriminability as a function of output interference. Output interference is the finding in recognition memory that discriminability decreases as more items are encountered during a test list. This is believed to occur because as test items are encoded into memory they produce interference with other items already stored in memory. A standard recognition paradigm was used where one condition consisted of all neutral (unrelated) items and the other condition consisted of half categorized (emotional words or animal names) and half neutral items. It was predicted that 1) there would be a larger memory bias for the categorized words, consistent with previous literature, and 2) that output interference would be stronger for categorized words because the relatedness of the items would make them more confusable in memory. As predicted, there was a memory bias for categorized words, such that there were increased hits and false alarms compared to neutral words. This memory bias changed across the test list, with participants becoming more conservative over the course of the test list, but the effect was similar for both categorized and neutral words. However, analyses for output interference showed the opposite trend than was predicted, such that neutral words were more influenced by output interference than categorized words. This finding challenges certain theories of output interference that suggest item confusability is the mechanism driving interference based on tested items. Overall these studies show that both memory bias and discriminability change across the test list in recognition memory, but in general these effects did not strongly differ between related, categorized items and unrelated, neutral items. These results will be discussed relative to theories and models of recognition memory, but future work is still needed to further understand the effects of stimulus effects on output interference and discriminability.

Visual Word Processing Efficiency for Chinese Characters and English Words

Yang, Cheng-Ta, Chen, Jay, Houpt, Joseph, Eidels, Ami, and Little, Daniel

Whether visual word processing involves part-based analytic processing or whole-based holistic processing has been debated over past decades. Due to the differences in the writing system (non-alphabetic as opposed to alphabetic), it is reasonable to speculate that Chinese characters may involve a higher degree of holistic processing than English words. We examined visual word processing efficiency, a reaction-time measure of the degree of holistic processing, while matching Chinese characters and English words, respectively. 54 Taiwanese students (Chinese as first language and English as second language) participated in a delayed matching task, where they were required to match the sameness and difference of a whole or a part of a Chinese character and an English word in separate sessions. Notably, in the whole-word condition, the test stimulus may differ from the memory stimulus in one (single-different) or two parts (both-different). In addition, word type (word, pseudo-word, and non-word) were manipulated. The capacity coefficient (for an AND task; Townsend & Wenger, 2004) was estimated by comparing the performance of same whole-word condition to the same part-word condition, and the capacity coefficient (for an OR task) was estimated by comparing the performance of both-different whole-word condition to the performance of the single-different whole-word condition.

Results showed that AND-capacity for English word and pseudo-word was larger than that for the English non-word, replicating previous findings of word and pseudo-word superiority effect. In contrast, OR-capacity for the English words showed opposite effect: Non-words result in larger capacity than words and pseudo-words. Interestingly, the AND-capacity and OR-capacity for the Chinese characters revealed a different effect. No differences were observed between the three types of characters for the AND-capacity, and Chinese words have larger OR-capacity than Chinese non-words. Our results suggest that Chinese characters and English words may involve different processing strategies and this visual word processing strategy may be modulated by the amount of information required for decision-making.

Hotel Map


FARRINGTON BOARDROOM
ANTE ROOM
JANEWAY
WALDRON
ARTWORK ROOM
MEYER
BISHOP
ARCHBALD
WAKSMAN
SCOTT
ELLIS
DICKSON
KILMER
LADIES
MERCHANT AMPHITHEATRE
VANDERBILT
PERKINS
ROOSEVELT
RARITAN RIVER CONFERENCE CENTER
KELLY KIOSK
ELLWICH LOBBY
CONCIERGE
BUSINESS CENTER
KELLY
NEILSON
JOHNSON
SEGAL KIOSK
SEGAL