48th annual meeting of the society for

mathematical psychology

Abstract Book

2015

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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 This section is automatically generated from the submission website and may not reflect recent updates, such as withdrawn contributions or changes in authorship.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 plenary presentations, then the symposium presentations, then the regular submitted presentations, and finally the posters.

Plenary presentations

Stability and plasticity in perceptual learning and models

Dosher, Barbara

Perceptual learning improves how we see visual stimuli and is the basis of visual expertise. This talk considers some predictions and tests of an integrated reweighting framework (Dosher et al., 2013) for how perceptual learning balances plasticity and stability of visual representations and accounts for broad phenomena in perceptual learning related to the role of feedback, the challenges of learning intermixed tasks, and the role of bias in situations that are non-stationary due to learning.

Reckoning with uncertainty: Learning to discern and adapt to the obscure

Hertwig, Ralph

How people should and do reckon with uncertainty is one of the most vexing problems in theories of choice. A number of solutions have been proposed. One is to simply assume, like Savage (1954) and Ramsey (1926) did, that for a 'rational' individual all uncertainties can be reduced to risks by replacing objective probabilities with subjective ones. However, there are at least three alternatives to this non-ecological perspective on human cognition, all of which emphasize the human mind's ability to learn as the key adaptive asset for navigating uncertainty. One is to intuit unknown probabilities from stored knowledge about the world.

Another is to infer unknown probabilities approximately from statistical regularities that govern real-world gambles. The third is to sample the world for information, even in a very limited way, so as to replace uncertainty with what Knight (1921) called statistical probabilities. This talk will focus on this third way to adapt to uncertainty and report on recent developments in research on decisions from experience.

Differentiation: A core mechanism underlying episodic memory

Criss, Amy H.

Differentiation originated in the perceptual learning, similarity, and categorization literatures and described the decrease in similarity between items as the amount of learning increased (e.g., Gibson & Gibson, 1955; Nosofsky, 1987, 1991; Saltz, 1963). Differentiation was originally adopted in theories of episodic memory to account for the list strength effect. Here we review evidence for differentiation in both behavioral and neural data and show that the principle of differentiation accounts for two seemingly unrelated empirical findings. Collectively these data demonstrate that differentiation is a core mechanism underlying episodic memory.

Cognitive latent variable models

Vandekerckhove, Joachim

We introduce cognitive latent variable models, a broad category of formal models that can be used to aggregate information regarding cognitive parameters across participants and tasks. Latent structures are borrowed from a vast literature in the field of psychometrics, and robust cognitive process models can be drawn from the cognitive science literature. The new modeling approach is an extension of hierarchical modeling, allows model fitting with smaller numbers of trials per task if there are multiple participants, and is ideally suited for uncovering correlations between latent task abilities as they are expressed in experimental paradigms. Multiple examples serve to illustrate the wide applicability of this hybrid approach.

Symposium presentations

Symposium on *Naturally Occurring Data Sets*

Goldstone, Robert

The very expertise with which psychologists wield their tools for achieving laboratory control may have had the unwelcome effect of blinding us to the possibilities of discovering principles of behavior without conducting experiments. When creatively interrogated, a diverse range of large, real-world data sets provides powerful diagnostic tools for revealing principles of human judgment, perception, categorization, decision making, language use, inference, problem solving, and representation. Examples of these data sets include web site linkages, dictionaries, logs of group interactions, image statistics, large corpora of texts, history of financial transactions, photograph repository tags and contents, trends in twitter tag usage and propagation, patent use, consumer product sales, performance in high-stakes sporting events, dialect maps over time, and scientific citations. The goals of this symposium are to present some exemplary case studies of mining large data sets to reveal important principles and phenomena in psychology, and to discuss the possible data sources, methodologies, and analysis techniques that can be effectively used in these investigations.

Harnessing Big Data to understand life-or-death decisions: distributions of death tolls govern sensitivity to human fatalities

Olivola, Christopher

How do people perceive and react to deadly events? If every human life is equally valuable then our responses should be proportional to the number of fatalities: The larger an event's expected death tolls is, the more "disutility" we should assign to it. Unfortunately, research has repeatedly demonstrated that people exhibit a diminishing sensitivity to human fatalities: As the number of casualties increases, each additional death seems less shocking to us. Although well documented, and despite its grave implications, the origin of, and psychological processes underlying, this tendency have not been well understood. Here I will present (and provide empirical support for) a process-based explanation of this diminishing sensitivity to death tolls, using Decision-by-Sampling theory. According to this theory, perceptions and decisions concerning deadly events are governed by the distribution of death tolls that people typically observe around them. A unique feature of Decision-by-Sampling is that it allows us to make a number of predictions about people's reactions to deadly events, even before we collect ANY responses from them. However, doing so requires being able to measure (or at least estimate) the distribution of death tolls that people are exposed to. This talk will illustrate how Big Data (concerning the distribution of death tolls) can both inform psychological

theory (Decision-by-Sampling) and advance our understanding of an important phenomenon (our diminishing sensitivity to human fatalities).

Communication in communities: Exploring subtle influences on language use in more than a million online reviews

Dale, Rick, and Vinson, David.

Recent studies of language use see it as an adaptive process, guided by communicative efficiency (Aylett & Turk, 2004; Jaeger, 2010; Jaeger & Snider, 2013; Pate & Goldwater, 2015). These perspectives – often anchored to measures from information theory (e.g., Jaeger & Levy, 2006; Piantadosi et al., 2012) – may serve as a bridge to similar perspectives on language that see it as a dynamic process adapting to various constraints ("Five Graces Group," 2009). These two theoretical frameworks, though distinct in their intellectual heritage, both recommend that language usage, as an adaptive behavioral process, may reveal subtle "echoes" of constraints that reflect these adaptive processes. These echoes may only be detectable with adequate data to identify their presence. Large sources of natural data provide treasure troves for exploring these subtle adaptive relationships. Here we describe ongoing exploration of over one million business reviews from Yelp (cf. Vinson & Dale, 2014a,b; in press). We explore the potential relationships between message valence, social community structure, and other variables and the communication that is transmitted among members of this community. Observed effects are small but statistically reliable, and do suggest that extra-linguistic factors relate to use of language. Importantly, though the results suggest small effects, if these effects hold across many generations, the relevance of these social principles may be quite impactful at longer timescales in shaping languages (e.g., Lupyan & Dale, 2010). We discuss the potential theoretical impact large natural data sets might have in the domain of language and communication.

Cognitive modeling explorations with crowd-sourced opinions

Lee, Michael, Selker, Ravi, and Iyer, Ravi.

The crowd-sourced opinion website ranker.com allows people to provide top-n lists for a wide variety of social, political, sporting, and other topics. Ranker receives approximately 20 million unique visitors each month, who collectively provide opinion data on tens of thousands of lists, each of which is an answer to a very specific question (e.g. "The Best Beer" or "The Best Qualities in a Person"), some of which can be thought of as predictions (e.g. "The Scariest Threats to the United States" or "The Worst NFL Teams in 2014"). The most common action on the Ranker site is to vote on whether a particular item belongs on a

particular list, which is done millions of times each month. In addition, thousands of visitors create individual top-n lists, either by generating lists from scratch, or by modifying existing lists. We present a number of cognitive modeling applications to Ranker data, including detecting changes in voting patters, and aggregating rankings using Thurstonian models.

Fitting a hierarchical LATER model to large-scale data in a Bayesian framework

Oravecz, Zita

The talk centers on analyzing data from a large-scale research project that uses web-based crowdsourcing to study Alzheimer's Dementia. We fit an extended Linear Approach to Threshold with Ergodic Rate (LATER) model for simple response time measures from Go/No-go task trials that participants completed through the web. The goal is to separate two distinct aspects of cognitive functioning: speed of information accumulation and caution in responding. Individual differences will be modeled through person-specific cognitive parameters. Moreover, the cognitive parameters will be made function of covariates (e.g., age, gender) to contribute to better understanding the sources of inter-individual variation. The Bayesian framework will allow us to estimate cognitive parameters and regression coefficients in a one-stage analysis.

The cognitive origins of Zipf's law

Piantadosi, Steven

Zipf's law is one of the most famous statistical facts about human language. In 75 years, we have worked out dozens of ways to derive it mathematically, both in the social and physical sciences. Each derivation provides a theory for why language appears Zipfian, yet little progress has been made in determining which existing theory–if any–is the correct one. I will first discuss work that attempts to disentangle the leading accounts using corpus methods. I'll show that despite the profusion of theories, none are clearly consistent with basic data about how language is used. I'll then present a simple behavioral experiment that gathers a large quantity of naturalistic language use. The experiment provides a strong case against all existing accounts. In general, Zipf's simple law provides a fascinating test case for thinking about the important properties of cognitive theories and how they may be evaluated with natural data.

Extracting Structures in Cross-Table Data

Zhang, Jun

A common and naturally occurring data format is "cross-table", where rows contain elements of a set (of authors, words, visual objects, etc) and columns contain subsets of these elements (papers written together, phrases, visual scenes, etc.). Such data can be represented as hyper-graphs, with nodes and hyper-edges connecting multiple nodes.There is a well-developed algebraic method for analyzing such data set, namely, Formal Concept Analysis. In this talk, after reviewing the basic construction of "concept lattice", I will show how to extract two binary relations on the elements of the ground set: a pre-order relation (from which notions of neighborhood, separation, local basis, etc can be defined) and a tolerance relation (from which notions of clique, covering, independence. etc can be defined). The above construction provides a more general setting than topological methods (in not requiring any a prior structure on the cross-table. The power of this methodology will be demonstrated using co-authorship network as an example.

Learning about movie preferences and forecasting abilities in the presence of missing data

Steyvers, Mark, Merkle, Ed, Mellers, Barbara, and Tetlock, Philip.

Missing data is a common problem in modeling and statistical inference. To analyze and learn from incomplete data, assumptions need to be made about the data generating process that generates complete data and the missing data process that explains which elements of the complete data will not be observed. We will present two case studies of naturally occurring data where it is important to include choice processes as part of the missing data process. The first case study is in the context of recommender systems (e.g. Netflix, Goodreads) where the goal is to learn about user preferences from a set of items (e.g. movies, books) that are rated by the user. The data are naturally occurring because the items to be rated are chosen by the user and are not randomly picked by an experimenter. We will present a topic model that includes a probabilistic process for the choice of items to rate as well as a process for selecting a rating for those items. These topic models can learn about user preferences from just knowing which items were rated even in the absence of any explicit ratings. The second case study is based on a large-scale forecasting tournament where users choose the forecasting problems they work on and for each problem, they provide a probabilistic forecast. We show how an Item Response Theory (IRT) can be generalized to not only handle continuous probabilistic forecasts but also the choice of items for which users forecast. We show how the selected forecasting problems from each forecaster provides a new source of data for

estimating forecaster ability. Generally, the two case studies suggest that missing data due to choice processes present computational challenges (how do we model the choice processes) but also opportunities to gain additional information from missing data.

Symposium on *Adaptive Risky Choice*

Pleskac, Timothy

Risky decisions occur in a variety of situations, each with its own demands. Some decisions offer plenty of time to reach a decision; others offer very little time. Some decisions come with full information; others offer very little information. Some decisions have options that are shaped by competitive forces; others offer very little structure. How do decision makers make choices in this ever-changing ecology of risky choice? The easy answer is that they adapt. That is, they change or adjust their processes to meet the requirements of the task at hand. But how does adaptation work, especially given that the constraints of the decision maker mean that the optimal strategy is rarely possible? This symposium will examine how computational modeling is starting to advance the scientific understanding of adaptive decision making, with a particular focus on risky choice.

An ecological analysis of the risk-reward relationship

Pleskac, Timothy, Conradt, Larissa, and Hertwig, Ralph.

In decisions under uncertainty the probabilities of payoffs are unknown but may be needed to reach a choice. One solution to this problem is to use a risk-reward heuristic inferring that probabilities are inversely related to payoffs. However, a heuristic is only adaptive if it reflects true stable ecological relationships. We show that low probabilities of high payoffs are ubiquitous. They are a consequence of an ecological principle where the number of competitors in a resource patch is proportional to the total amount of resources in it, an ideal free distribution of competitors. This principle implies that the probability of obtaining a large resource item is low and thus large payoffs predict low probabilities. However, it also suggests that small rewards are not necessarily tied to larger probabilities. Another implication is that a high probability implies a low payoff, but not vice versa.

Modeling choice and search in decisions from experience: A sequential sampling approach

Markant, Douglas, Pleskac, Timothy, Diederich, Adele, Pachur, Thorsten, and Hertwig, Ralph.

Research on "decisions from experience" (DFE) aims to understand how predecisional exploration influences a person's ultimate choice between a set of options. Although a number of existing models can account for how sampled experiences relate to choice, they do not explain people's decisions about how to explore (in particular, when to stop sampling information and make a consequential choice). This gap is especially notable in light of evidence that people adapt their exploration to different circumstances, collecting larger samples when they experience greater variability in outcomes, when higher payoffs are at stake, or when sampling costs are low. We propose that both exploration and choice in DFE can be understood as arising from a sequential sampling process whereby decision makers accumulate information to form a preference over options, and terminate sampling when their preference crosses a chosen threshold. This approach predicts how both exploration and choice depend on the interaction between the probabilistic structure of choice options and psychological properties of the decision maker. Moreover, it offers a framework for understanding a variety of disparate findings in DFE as arising from an adaptive search process.

The ecological rationality of heuristics in decisions from experience

Woike, Jan K., Ralph, Hertwig, and Thorsten, Pachur.

Traditionally, the normative approach to making decisions between options under risk focuses on adding the products of an option's possible outcomes with their probabilities. In decisions from experience, however, outcomes and probabilities have to be estimated, often based on small samples, so that it may be adaptive to use simplifying principles of integration. In computer simulations, we compare the performance of expectation-based mechanisms and several heuristic approaches (e.g., equal weighting or minimax) under states of decreasing uncertainty, implemented as increasing sample sizes. We demonstrate that expected value calculation is not necessarily the best-performing strategy. We further analyze the ecological rationality of heuristics by studying their performance under several manipulations of the task, such as varying the number of outcomes, or outcome and probability distributions.

Risk Sensitivity as an Evolutionary Adaptation

Hintze, Arend

Making a claim about the evolutionary origins of a human behavior is easy, having empirical evidence to back up that claim is hard, making an evolutionary experiment using natural organisms and identifying the causal relations between evolutionary selection pressures and behavior is almost impossible. Computational modeling of evolutionary processes or evolutionary agent based modeling on the other hand can test evolutionary hypothesis directly. Here we explore how one can use such a computational approach to make inference about the evolutionary origins of human risk sensitivity. We show that risk aversion can evolve in small groups, and that it requires decisions about rare events that have a large impact on the individual's fitness such as mating and mate competition for example.

Prospect theory tracks selective allocation of attention

Pachur, Thorsten, Schulte, Michael, and Hertwig, Ralph.

Cumulative prospect theory (CPT), arguably the most prominent model of decision making under risk, has been almost completely detached from cognitive decision research, that focuses on measuring predecisional cognitive processing. We highlight that key explanatory constructs in CPT, such as probability sensitivity and loss aversion, are amenable to an information-processing interpretation in terms of selective attention allocation. Given that attention allocation often changes in response to task properties, CPT might thus be able to capture adaptive decision making. In a process-tracing study, we monitored people's information search while they chose between monetary lotteries and estimated CPT parameters from each participant's choices using a Bayesian hierarchical approach. Individual differences reflected in CPT's probability sensitivity, outcome sensitivity, and loss aversion parameters were associated with individual differences in selective attention during information search-such as the relative attention to probabilities versus outcomes and the relative attention to negative versus positive outcomes. Our results reveal an underappreciated value of CPT to reflect aspects of cognitive processing, potentially including adaptive processes of decision making.

Symposium on *20 Years of Systems Factorial Technology*

Little, Daniel R., Fific, Mario, Yang, Cheng-Ta, and Altieri, Nicholas.

2015 is the 20th anniversary of the publication of Townsend and Nozawa's (1995) landmark paper "Spatio-temporal properties of elementary perception: An investigation of parallel, serial, and coactive theories." This paper introduced a novel set of theoretical and methodological tools, termed Systems Factorial Technology, which allows researchers to answer several fundamental questions central to the basic information processing abilities underlying fundamental psychological behaviors such as detection, identification, classification, recognition, and decision making. This paper provided tools which allowed researchers to unambiguously and simultaneously tease apart properties which were notorious difficult to identify. These properties include whether information processing occurs in serial or parallel, whether the capacity of information processing is limited or unlimited or even supercapacity, whether information is processed independently, and whether all available information is processed prior to making a decision. Systems Factorial Technology solved the serial/parallel mimicking dilemma that had been plaguing the area of cognitive psychology for more than a half century. The past five years have seen a near-exponential increase in the use, development, and application of this methodology. The goal of this symposium will be to highlight recent advances and applications of SFT.

Simple Factorial Tweezers for Detecting Delicate Serial and Parallel Processes

Fific, Mario

Over the last fifty years, work regarding the theoretical foundations governing the organization of mental processes has centered on the formal properties of various hypothesized mental networks. Such networks are defined in terms of their fundamental properties: processing order, stopping rule, and process dependency. Pivoting on the work of James Townsend, Richard Schweickert and Ehtibar Dzhafarov, these efforts resulted in the creation of the Systems Factorial Technology (SFT) - a suite of methodological tools for directly investigating the fundamental properties of cognitive operations. The SFT approach rests on rigorously tested mathematical tools for discriminating between serial and parallel processing, exhaustive and self-terminating stopping rules, and stochastic independence and dependence, as well as for discerning the capacity of an investigated system, all in a non-parametric (distribution-free) manner. The present study is focused on further refining recent advances in SFT methodology (Yung, Fific, Townsend, 2014), and on the development of new tools for use with larger mental networks. The present study also seeks to integrate these advances with the factorial tools developed to explore non-homogenous mental networks, which may consist

of both serial and parallel processes (so called serial/parallel networks Schweickert, Giorgini & Dzhafarov, 2000; Dzhafarov, Schweickert, & Sung, 2004).

Noncontextuality with Marginal Selectivity in Reconstructing Mental Architectures

Zhang, Ru, and Dzhafarov, Ehtibar N.

We present a general theory of series-parallel mental architectures with selectively influenced stochastically non-independent components. A mental architecture is a hypothetical network of processes aimed at performing a task, of which we only observe the overall time it takes under variable parameters of the task. It is usually assumed that the network contains several processes selectively influenced by different experimental factors, and then the question is asked as to how these processes are arranged within the network, e.g., whether they are concurrent or sequential. One way of doing this is to consider the distribution functions for the overall processing time and compute certain linear combinations thereof (interaction contrasts). The theory of selective influences in psychology can be viewed as a special application of the interdisciplinary theory of (non)contextuality having its origins and main applications in quantum theory. In particular, lack of contextuality is equivalent to the existence of a "hidden" random entity of which all the random variables in play are functions. Consequently, for any given value of this common random entity, the processing times and their compositions (minima, maxima, or sums) become deterministic quantities. These quantities, in turn, can be treated as random variables with (shifted) Heaviside distribution functions, for which one can easily compute various linear combinations across different treatments, including interaction contrasts. This mathematical fact leads to a simple method, more general than the previously used ones, to investigate and characterize the interaction contrast for different types of series-parallel architectures.

A Parallel Interactive Explanation of Audiovisual Integration and the McGurk Effect

Altieri, Nicholas, Lentz, Jennifer, and Townsend, James T.

One of the most poignant and commonly cited examples of audiovisual speech integration is the "McGurk effect" introduced by McGurk and Macdonald in 1976. The classical instantiation of this effect occurs when a listener is presented with mismatched auditory-visual speech signals: typically, the auditory consonant "b" combined with a visually articulated "g". This paper proposes a novel approach for quantifying the amount of integration relative to parallel independent models as "attention" is manipulated. To that end, capacity

(Townsend & Nozawa, 1995) and integrated hazard ratios were assessed in a within-subject experiment: a divided and a focused attention study. Results indicated that visual speech cues influenced auditory consonant perception when listeners divided attention across modalities, and also when they attempted to ignore the visual modality while focusing exclusively on the auditory. To explain these findings, it is argued that facilitatory and inhibitory parallel cross-talk operates automatically across the auditory and visual modalities as speech recognition unfolds.

Modeling Stroop Performance in Cognitive Neuroimaging of Schizophrenia: A Case Study of Systems Factorial Technology in Clinical Science

Taylor, Reggie, Theberge, Jean, Williamson, Peter, and Neufeld, Richard W. J.

We analyze performance of Schizophrenia (Sch), Mood-disorder (MD) and Healthy-Control participants on a Stroop Task undertaken during model-based 7-T fMRI. The Stroop is perhaps the most widely used cognitive task in the field of cognitive science, including clinical cognitive science (Eidels, Townsend & Algom, 2010). The present work thus extends past findings of schizophrenia stimulus-encoding impairment to this prominent task, and exploits SFT to estimate certain dynamics of performance. Stroop conditions were "Color Only" (CO; color patch); "Word Only" (WO; color name in white, against a black background); "Congruent" (color name printed in the named color); and "Incongruent" (color name printed in a different color). The Congruent condition was a double target, and the other 3 were versions of SFT single-target conditions. As with Eidels, et al, super-capacity was absent throughout. There was some indication of an independent-channel hoarse-race architecture for controls (as in Eidels, et al). SFT analysis indicted cross-channel impedance in MD, and Sch-specific CO-WO equivalence, but contraindicated selected past findings of Sch-specific cross-channel facilitation. In agreement with previous clinical modeling, the most parsimonious account was one of intact cognitive-workload capacity at the level of an individual cognitive operation (subprocess), but with progressively more subprocesses with MD and Sch. status. This is analogous to a single hoarse running at normal speed, but closer to the outside rail– resulting in a greater distance (more strides) to the finish. SFT's capacity indexes are shown to provide a common metric for the expression of heterogeneous sources of clinical cognitive deficit. Because of their own symptom significance, results broker the same to deviant neurocircuitry, monitored during Stroop performance. Issues of inter-participant performance heterogeneity within groups, and validity of invoked parametric latency distributions are addressed.

Exploring Individual Differences in Capacity Coefficients with Statistical Learning

Blaha, Leslie M., and Houpt, Joseph W.

A strength of the Systems Factorial Technology (SFT) approach is that the model-based measures are applied at the individual participant level, enabling detailed characterizations of each observer's information processing mechanisms. For example, the well-established capacity coefficient assesses changes in performance with changing workload demands. It does so by comparing performance with multiple sources of information together to performance on each of those information sources in isolation. The measure is a function across time and can potentially carry a large amount of information about a participant. Unfortunately, in many applications, this information has been ignored, either by using qualitative verbal assessments of the function or by using a single summary statistic. Recent work demonstrated the efficacy of dimensional reduction, particularly functional principal components analysis, for extracting important information about the capacity function. We extend this work by applying additional techniques from statistical learning, including K-means and hierarchical clustering, to examine individual differences. We will discuss applications to data from multiple past studies, identifying individual differences driven by experimental conditions, clinical groups, and perceptual learning. We highlight how statistical learning approaches can extend the analytic power of SFT measures for inferences about both individual participants' processing mechanisms and trends or groupings among the participants based on principled evaluation of individual differences.

Semi-parametric Bayesian Approaches to Systems Factorial Technology

Houpt, Joseph W., Van Zandt, Trisha, and Townsend, James T.

Empirical response time density and distribution functions all look quite similar (e.g., unimodal, positively skewed) and are consistent with a number of different possible theoretical data-generating distributions. Luce (1986), contemplating this problem, showed how two variables with very similar probability density functions had very different and discriminable hazard functions. In addition, Townsend and colleagues have developed a number of "functionals'' that use the integrated hazard function to determine different characteristics of multi-channel processing systems (e.g., Townsend & Nozawa, 1995). The problem is that hazard functions and the systems factorial technology functionals must be estimated from the data, and they are therefore random functions with considerable variability. How can this variability be accommodated, so that arguments about plausible and implausible models can be supported? Some methods derived from Gaussian process theory have been proposed

(Houpt & Townsend, 2010; Houpt & Townsend 2012). In this paper we suggest an alternative approach, and that is to compute the posterior estimates of the hazard function, and the functionals that can be computed from it, including the survivor function interaction contrast and the capacity coefficient. We can then compute posterior estimates of different statistics that reflect different behaviors of the functionals, and so arrive at a fully Bayesian and theoretically-motivated approach to systems factorial technology.

Exogenous and endogenous cues differentially influence the processing architecture during perceptual decision making

Chang, Ting-Yun, Yu, Ju-Chi, Little, Daniel R., and Yang, Cheng-Ta.

There are numerous exogenous (bottom-up, stimulus-driven) and endogenous (top-down, goal-derived) cues which guide attention and thereby influence perceptual decision. Yang, Little, and Hsu (2014) showed that the validity of an exogenous cue in a cued detection task influences whether attention is diffuse or focused. That is, parallel processing was observed when the cue did not provide any information about the target location, but serial processing was observed when the cue perfectly predicted the target location. In the present study, we examined whether varying the validity of an endogenous cue also results in a change in the perceptual decision making architecture. Two validity conditions (100% or 50%) were counterbalanced across six participants. Results showed that the strategies of the participants who first performed the 50% validity condition shifted from parallel processing to serial processing as the cue validity varied. By contrast, participants who first performed the 100% validity condition adopted serial processing regardless of the cue validity. The current results demonstrated that prior experience with the endogenous cue was central to determining the attentional strategy, hence, highlighting a key difference between exogenous cues and endogenous cues and highlighting the role of controlled processing in selecting a decision strategy to optimize the cued detection performance.

Systems factorial technology provides new insights on the other-race effect

Yang, Cheng-Ta, Fific, Mario, and Chang, Ting-Yun.

Although perceiving and recognizing a face is a fundamental function of human vision, people may have difficulty in discriminating between faces from ethnic and racial groups other than their own. This effect is termed as the other-race effect. Previous studies have suggested that other-race faces may be processed less holistically than own-race faces; however, inconsistent results were observed across tasks. Here, we followed the suggestions of systems factorial technology (Townsend & Nozawa, 1995) to examine the cognitive processes for Taiwanese

participants in categorizing own-race (Taiwanese woman) and other-race (Caucasian woman) faces according to their nose-to-mouth separation and eye-to-eye separation. Results showed that most participants adopted parallel, self-terminating processing in categorizing own-race faces; by contrast, most participants adopted serial, self-terminating processing in categorizing other-race faces. These results provide supports for holistic processing for own-race faces; that is, own-race faces are taken as a whole such that all the features are processed simultaneously (in parallel) for decision-making. Alternatively, other-race faces are processed in an analytic manner, namely, a sequential feature-by-feature processing. The current results provide new insights on the individual differences in face processing.

Beyond Shannon entropy: a unified mathematical framework for entropy measures and its importance for understanding human active learning

Nelson, Jonathan D., Crupi, Vincenzo, Meder, Bjoern, Cevolani, Gustavo, and Tentori, Katya.

One of the most important kinds of decisions that people make are decisions about which test (or experiment) to conduct next. For instance, in medical diagnosis, a carefully chosen test can helpfully narrow the range of plausible diseases that the patient might have. In a probabilistic framework, test selection can often be predicted with the idea that people have the goal of reducing entropy (uncertainty) in their beliefs about the possible states of the world. For instance, the goal could be to conduct the test that in the expectation will lead to lowest posterior uncertainty (entropy) about the patient's true illness.

In psychology and medical decision making, reduction in Shannon entropy (information gain) is predominant. But a variety of entropy metrics (Hartley, Tsallis, RÃl'nyi, Arimoto, Quadratic) are popular in different fields within the social sciences, the natural sciences, artificial intelligence, and the philosophy of science. Particular entropy metrics have been predominant in particular fields; it is not clear when particular measures' predominance in an individual domain may be due to historical accident.

We show that many entropy and information gain measures arise as special cases in the Sharma-Mittal family of entropy measures. Using mathematical analyses, analysis of earlier human behavioral data, and simulations, we address:

(1) How do these different entropy models relate to each other? What insight can we obtain by considering the individual entropy models within this unified framework?

(2) What is the psychological plausibility of each possible entropy model?

(3) What important new questions for empirical research arise from these analyses, both with human subjects and in applied domains?

Extracting Structures in Cross-Table Data

Zhang, Jun

A common and naturally occurring data format is "cross-table", where rows contain elements of a set (of authors, words, visual objects, etc) and columns contain subsets of these elements (papers written together, phrases, visual scenes, etc.). Such data can be represented as hypergraphs, with nodes and hyper-edges connecting multiple nodes.There is a well-developed algebraic method for analyzing such data set, namely, Formal Concept Analysis. In this talk, after reviewing the basic construction of "concept lattice", I will show how to extract two binary relations on the elements of the ground set: a pre-order relation (from which notions of neighborhood, separation, local basis, etc can be defined) and a tolerance relation (from which notions of clique, covering, independence. etc can be defined). The above construction provides a more general setting than topological methods (in not requiring any a prior structure on the cross-table. The power of this methodology will be demonstrated using co-authorship network as an example.

Modeling the wandering mind: Informing sequential sampling models with neural data

Hawkins, Guy E., Mittner, Matthias, Boekel, Wouter, Heathcote, Andrew, and Forstmann, Birte.

People often "mind wander" during everyday tasks, temporarily losing track of time, place, or current task goals. Such lapses of attention are particularly likely during repetitive tasks, including psychological experiments. On the basis of behavioral data alone, such as choices and response times, reliably identifying latent task-related or mind-wandering states can be difficult or near impossible. Here, we consider mind wandering as a neural state or process that affects the parameters of cognitive models, which in turn affects observed behavioral performance. Through the lens of cognitive models of speeded decision-making, we consider two approaches that use neural data to constrain cognitive models which in turn help to identify when people mind wander and the effect it has on task performance. The first approach assumes that observed performance arises from a discrete mixture of latent on-task and off-task states. The second approach regresses single-trial measures of neural activity onto structured trial-by-trial variation in the parameters of cognitive models. We contrast the two approaches, and the questions they can answer, and highlight that both approaches allow neural data to provide additional constraints on the parameters of cognitive models, providing a more precise account of the effect of mind wandering on behavior. We demonstrate the approaches with an application to data from a perceptual decision-making experiment using

EEG and thought sampling methods to monitor mind wandering during task completion.

Simple Factorial Tweezers for Detecting Delicate Serial and Parallel Processes

Fific, Mario

Over the last fifty years, work regarding the theoretical foundations governing the organization of mental processes has centered on the formal properties of various hypothesized mental networks. Such networks are defined in terms of their fundamental properties: processing order, stopping rule, and process dependency. Pivoting on the work of James Townsend, Richard Schweickert and Ehtibar Dzhafarov, these efforts resulted in the creation of the Systems Factorial Technology (SFT) – a suite of methodological tools for directly investigating the fundamental properties of cognitive operations. The SFT approach rests on rigorously tested mathematical tools for discriminating between serial and parallel processing, exhaustive and self-terminating stopping rules, and stochastic independence and dependence, as well as for discerning the capacity of an investigated system, all in a non-parametric (distribution-free) manner. The present study is focused on further refining recent advances in SFT methodology (Yung, Fific, Townsend, 2014), and on the development of new tools for use with larger mental networks. The present study also seeks to integrate these advances with the factorial tools developed to explore non-homogenous mental networks, which may consist of both serial and parallel processes (so called serial/parallel networks Schweickert, Giorgini & Dzhafarov, 2000; Dzhafarov, Schweickert, & Sung, 2004).

Submitted presentations

A Bayesian Implementation of General Recognition Theory

Danileiko, Irina, Lee, Michael, and Kalish, Michael.

Decision-bound models in category learning are based on the assumption that participants in a categorization task split the stimulus space into two competing response regions. This is in contrast to exemplar models, which assume that each stimulus is held in memory and referenced when categorizing something novel. One successful decision-bound model is General Recognition Theory (GRT: Ashby & Townsend, 1986), which has been applied to multidimensional categorization data by maximum likelihood estimation and BIC model comparison. We propose an implementation of GRT in a Bayesian framework as a latent mixture model that infers each person's decision bound. We apply our model to a number of categorization data sets. Participants make these categorization decisions as a result of either a diagonal, horizontal, or vertical boundary in the stimulus space. Our Bayesian GRT infers which of these boundaries a person is using, as well as accounting for different types of contaminants in the data set. We show that an application of a Bayesian framework to this type of cognitive model allows us to investigate individual differences in people's categorization performance, such as varying strategies of decision boundaries or different explanations of apparent guessing behavior. We discuss applications of the Bayesian implementation of GRT, including to wisdom of the crowd problems that rely on the effective use of individual differences.

A Bayesian framework for ability estimation in adaptive educational games

Verhagen, Josine, and Liu, Solomon.

Estimating player ability from adaptive educational games comes with many challenges. The information available per play session is often sparse, while combining information across play sessions requires taking into account changes in ability between play sessions. Ideally, information from previous gameplay is taken into account in such a way that more recent and more precise information is weighted more heavily. A Bayesian framework will be presented which combines state-space, time decay, and psychometric models. A transition function combines the posterior distribution after the previous challenge with a noise function to form the prior for the next challenge, where the transition weight for the posterior distribution is modeled with a time decay function. As a result, as time passes between play sessions, the prior for the next challenge goes "back" to the prior when no information about previous gameplay is present, which serves as the noise function. This noise function prior can be uninformative, or it can take into account other information, such as age or scores on related games. The approach will be illustrated with data from an adaptive game for preschoolers

aimed to teach shape and color recognition.

A Bayesian hierarchical model of crowding: a case study of global-local processing in visual perception

Zhang, Shunan, and Yu, Angela.

We explore the interaction between global-local information processing in visual perception, using a visual phenomenon known as crowding, whereby the perception of a target stimulus is impaired by the presence of nearby flankers. The majority of established models explain the crowding effect in terms of local interactions. However, recent experimental results indicate that a classical crowding effect, the deterioration in the discrimination of a vernier stimulus embedded in a square, is alleviated by additional squares ("uncrowning"). Here, we propose that crowding and uncrowding arise from abstract neural inferences about hierarchically organized groups, and formalize this hypothesis using a hierarchical Bayesian model. We show that the model reproduces both crowding and uncrowding; more generally, the model provides a normative prescription for how visual information might flow bottom-up, top-down, and laterally, to allow the visual system to simultaneously and interactively process global and local features in the visual scene.

A Bayesian hierarchical model of lexicographic choice

Park, Sanghyuk, and Davis-Stober, Clintin.

I present a lexicographic, threshold-based model of choice used to evaluate decision makers' preferences among risky alternatives. Using a hierarchical Bayesian framework, this model is able to account for observed individual differences by allowing for variable threshold values in attribute features, as well as allow individual differences in the order that individuals consider attributes of the choice alternatives. Performance of the model is evaluated via a parameter recovery test using simulated data. I also apply the model to new choice data from a decision making under risk experiment. I discuss the advantages of a hierarchical Bayesian framework in modeling individual differences in choice.

A Hierarchical Bayesian Approach to Autonomous Adaptive Experimentation

Myung, Jay, Gu, Hairong, Kim, Woojae, Hou, Fang, Lu, Zhong-Lin, and Pitt, Mark.

The accurate and efficient measurement of observations is at the core of empirical scientific

research. To ensure measurement episodes are also optimal, and thereby maximize inference, there has been a growing interest by researchers in the design of adaptive experiments that lead to rapid accumulation of information about the phenomenon under study with the fewest possible measurements. Further, in an autonomous adaptive experiment, the design and execution of an experiment are performed with minimal intervention by scientists after the experiment is initiated. Our lab has recently developed a hierarchical Bayesian approach for autonomous adaptive experimentation, dubbed hierarchical adaptive design optimization (HADO), that provides a judicious way to exploit two complementary schemes of inference (with group and individual data) in a statistically justified manner. In this talk, after a brief introduction of the HADO scheme, we present and discuss results from an empirical validation study to evaluate the benefits of HADO in the adaptive estimation of the contrast sensitivity function in visual psychophysics.

A Nonlinear Ordinary Differential Equation Model of Emotion.

Ou, Lu, and Chow, Sy-Miin.

Human emotions are often regarded as a complex system that shows changes as driven by both intrinsic as well as extrinsic factors. One possible way of representing complex systems that show within- as well as between-person variations over time is to use differential equation models with mixed effects in the parameters (Chow, Lu, Sherwood, & Zhu, 2014). We propose a bivariate nonlinear ordinary differential equation (ODE) model describing individuals' dynamic changes in positive emotion (PE) and negative emotion (NE) as two coupled nonlinear oscillators. In particular, we assume that the extent to which PE (or NE) is coupled to the other process is moderated by their current intensity levels. This was motivated by contemporary theories of affects which posit that emotions that are independent of each other may collapse into polar ends of a single dimension under high stress and activation levels. To obtain maximum-likelihood estimates of the parameters and their standard errors, we present a Continuous-Discrete Adaptive Extended Kalman Filtering approach (Kulikov & Kulikova, 2014) for model estimation purposes. The proposed model and estimation approach are evaluated using a Monte Carlo simulation study and applied to a set of daily diary data from the Affective Dynamics and Individual Differences (Emotions and Dynamic Systems Laboratory, 2010) study. Finally, we discuss possible applications of the proposed model and estimation approach to other areas in psychological sciences.

Chow, S.-M., Lu, Z., Sherwood, A., & Zhu, H. (2014). Fitting nonlinear ordinary differential equation models with random effects and unknown initial conditions using the stochastic approximation expectation–maximization (SAEM) algorithm. Psychometrika, 1–33.

Kulikov, G. Y. & Kulikova, M. V. (2014). Accurate numerical implementation of the continuous-discrete extended kalman filter. IEEE Transactions on Automatic Control, 59 (1).

Emotions and Dynamic Systems Laboratory (2010). The affective dynamics and individual differences (ADID) study: developing non-stationary and network-based methods for modeling the perception and physiology of emotions. Unpublished manual, University of North Carolina at Chapel Hill.

A Stochastic Approximation Expectation Maximization Theorem with Applications for Adaptive Learning, Adaptive Control, Markov Fields, and Missing Data Analysis

Golden, Richard M.

The goal of this paper is to introduce a classical Stochastic Approximation Theorem to support stochastic convergence analysis of discrete-time adaptive learning systems in both finite-state and continuous-state spaces whose assumptions, proof, and conclusions are relatively transparent.

In this talk, which is an extension of my 2014 presentation at last year's Mathematical Psychology conference, I introduce a theorem for stochastic convergence analysis of adaptive learning algorithms based upon classical arguments (e.g., Blum, 1954; Kushner, 2010). This particular Stochastic Approximation Expectation Maximization Theorem is applicable to both discrete-state and continuous state Markov Chain statistical environments in which environmental characteristics are possibly functionally dependent on the learning machine's behavior. The benefits of this theorem are that the assumptions and conclusions are easily interpretable and broadly applicable yet the theorem is broadly applicable. After stating the assumptions and conclusions of the theorem, the proof of the theorem is briefly sketched.

The relevance of the theorem is then discussed with respect to five areas. First, modeling adaptive learning in passive statistical environments where the actions of the organism do not change the environment's statistics. For example, the classical Rescorla-Wagner model (or equivalently Widrow-Hoff model) of adaptive learning has been applied to modeling a wide range of behavioral, cognitive, and neural phenomena. Second, an adaptive learning version of the widely used Expectation Maximization algorithm. Third, learning parameters of Hidden Markov random fields which are used in computer vision models as well as the analysis of brain imaging data. Fourth, learning parameters of probability models in the presence of missing data. And fifth, learning adaptive nonlinear control laws and adaptive critics in active statistical environments where the actions of the organism immediately alter the environmental statistics.

A Stochastic Lambda Calculus for the MDL Principle

Purdy, Brendan Patrick

This presentation is a follow-up to Purdy & Batchelder (J Math Psych 2009) and Purdy (Math Psych Conference 2011) in the sense that we will again use the tools of formal systems to better understand the structure and properties of statistical models that are used in the cognitive sciences. The focus of this presentation is on the Minimum Description Length (MDL) Principle. The MDL Principle can be described as follows: given a set of hypotheses H and a data set D, we should try to find the hypothesis or combinations of hypotheses in H that compress D the most. We will construct a stochastic lambda calculus (in the manner of Church) that incorporates the MDL Principle. We will then then use this lambda calculus, and other related formal theories, to derive properties about the MDL.

A cognitive latent variable model of decision making on optimal stopping problems

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

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. We present a new hierarchical threshold 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. Using Bayesian graphical modeling methods, we apply the model to previous data involving 101 participants with large individual differences in measures of cognitive abilities dimensions and intelligence who completed sets of length 5 and length 10 optimal stopping problems. Our results demonstrate the effectiveness of the bias-from-optimal model and find stable individual differences in thresholds that people use across both tasks. Furthermore, we relate those stable individual differences in deviations from optimal to the intelligence measures through the cognitive latent variable model.

A comparison of exemplar-based and decision bound models of response time in Garner's filtration and correlation conditions

Little, Daniel R., Wang, Tony, and Nosofsky, Robert M.

A large number of converging operations suggest that, unlike separable dimensions, integral dimensions are processed holistically. This difference has been convincingly demonstrated by Garner's (1974) classic study which showed that integral dimensions, but not separable dimensions, tend to interfere with each other if one of the dimensions must be ignored but

tend to facilitate one another if the dimensions are varied in a correlated manner. One key aspect of Garner's results is that item and response repetitions resulted in faster response times. Here we report an experiment in which we increased the number of stimuli to reduce stimulus repetitions. Nonetheless we find clear recency effects in both response time and accuracy. We test three models of category choice response times including both exemplar-based and General Recognition Theory models, but also a modern version the distance from boundary theory in which utilizes an integrated array of linear ballistic accumulators. Model comparison results and the theoretical implications of the recency effects will be discussed.

A dynamic model of inductive reasoning and visual memory

Hayes, Brett K., Hawkins, Guy E., and Heit, Evan.

Models of inductive reasoning have generally neglected the time course of inductive judgments. We conceive of induction as a dynamic process and provide a fine-grained examination of the distribution of response times observed in inductive reasoning. We used these data to develop and empirically test a linear ballistic accumulator model (Ex-LBA) that describes how items are compared in induction and how decisions about property generalization are made. The model assumes that the similarity between novel test probes and items stored in memory drive an accumulation-to-bound sequential sampling process: test probes with high similarity to studied exemplars are more likely to trigger a generalization response, and more rapidly, than items with low exemplar similarity. We contrast data and model predictions for inductive decisions with a recognition memory task using a common stimulus set. Hierarchical Bayesian analyses across two experiments demonstrated that inductive reasoning and recognition memory differ in the threshold to trigger a decision: observers required less evidence to make a property generalization judgment (induction) than an identity statement about a previously studied item (recognition), suggesting that induction might represent a âĂŸless cautious' form of recognition.

A linear approximation of the unequal variance likelihood ratio transformation and a linear ballistic accumulator model extension

Osth, Adam, Heathcote, Andrew, and Dennis, Simon.

Glanzer, Hilford, and Maloney (2009) argued for the basis of a log likelihood ratio transformation of memory strengths on the basis of several regularities in recognition memory, including the mirror effect, the zROC length effect, and the variances effect. They found that the three regularities held regardless of whether the distributions of memory strength were normal, binomial, or exponential in shape. Despite the power of such a transformaiton,

when memory strength distributions are normal and possess unequal variance, the transfer function from memory strength to log likelihood ratio is both nonmonotonic and quadratic in shape, resulting in log likelihood ratio distributions that are noncentral chisquare in shape. We present a linear approximation of this transformation via the Taylor series, which results in log likelihood ratio distributions that are normal in shape. In advantage of this transformation is that it allows the transformation to be applied to the Linear Ballistic Accumulator (LBA: Brown & Heathcote, 2008) model, which requires normal distributions for the drift rate. The results of a hierarchical Bayesian model selection procedure strongly favor a likelihood ratio version of the LBA over an unequal variance memory strength model due to the greater parsimony in explaining the mirror effect.

Addressing Very Short Stimulus Encoding Times in Modeling Schizophrenia Cognitive Deficit

Cutler, Colleen Diane, and Neufeld, Richard W. J.

It is well known that stimulus encoding times in persons with schizophrenia are longer than those of normal controls. Neufeld and various coauthors have argued that this is the consequence of additional subprocesses being executed during the encoding process in the case of schizophrenia. In general they expressed an encoding time as the sum of k' independent exponentially-distributed subprocesses, each executed with common rate v. The values of k' and v are fixed for each individual but allowed to vary over the population. An interesting and troubling consequence of their application of this model to real data was that under some circumstances some individuals appeared to encode virtually instantaneously; that is, mathematically k'=0 for a segment of the population. This was accommodated in Neufeld et al. by placing a Poisson distribution on k' which allowed for positive mass at 0, but did not explain how k'=0 is possible. In this paper we take the view that k'=0 is not realistic and develop an alternative model where k' can be restricted to positive integers (specifically we focus on a geometric distribution for k') so that instantaneous encoding is mathematically prevented. This is made compatible with fast observed encoding times by introducing a parameter alpha into the subprocess distribution which can be interpreted as a task parameter (it varies with the difficulty of the task being encoded). Each subprocess now follows a gamma distribution with parameters alpha and v rather than an exponential distribution. Small values of alpha correspond to fast subprocess encoding times. We then focus on estimating alpha and other distributional parameters from encoding time data. The key here is to consider individual participant performance and not collapse data across participants. We obtain theoretical solutions to the estimation questions, and illustrate them using numerical simulations. This development shows that very short encoding times can be made compatible with the model

of increased subprocesses in schizophrenia and in line with empirical findings. However, we concede that these theoretical solutions may not compatible with the small sizes of typical psychological data sets and thus present a challenge for future directions.

Aging slows retrieval of temporal information from working memory

Kilic, Asli, Sayali, Ceyda, and Oztekin, Ilke.

To evaluate the impact of aging on memory search operations, we investigated the retrieval of temporal order information from memory. Young and older adults completed a widely used paradigm to assess temporal order memory, namely the relative judgments-of-recency (JOR) task. In each trial, participants studied 5-item lists and were presented with two probes from the study list. Participants indicated the probe that had appeared more recently in study list. Analyses of accuracy data showed that young adults were more successful in correctly detecting the more recent probe compared to older adults. To evaluate the retrieval dynamics, we applied Hacker's (1980) serial scanning model to accuracy and reaction time data. Results from the model fits revealed that older adults were slower in engaging in the serial memory search operations required to access temporal order information.

An Alternative Notion of Topological Convergence

Lei, Yinbin, and Zhang, Jun.

Convergence of a sequence is a central notion in mathematics, and it plays a fundamental role in characterizing the limiting behavior of dynamical processes. The concept of a Cauchy sequence, which is rooted in the standard definition of topological convergence (in first-countable spaces), invokes the idea of (topological) neighborhoods. More precisely, a sequence x_n, n=1,2,... of points converges to a limit point x_0 if, for any neighborhood of x_0, there exists an N such that all of the points x_n, n=N,N+1,... fall within that neighborhood. We call this C-convergence. Though defined statically without mentioning time and built upon a sense of closeness near a point, Marghetis and Nunez (2013, Topics in Cognitive Science, 5, 299-316) argued that this convergence notion involved cognitive embodiment of continuity and limits; it is a dynamic expression of "tending to a limit" as revealed by human gestures. In the present work, we show that there can be an alternative notion of convergence (D-convergence): a sequence x_n, n=1,2,... of points converges to a limit point x_0 if there exists an N such that all of the points x_n, n=N,N+1,... fall within every neighborhood of x_0. Compared with C-convergence, D-convergence reflects finiteness property - it will be shown that any D-convergent sequence of points is finite (and hence has a unique limit point) if and only if the underlying topology is T_1 separable (i.e., all points have discrete

order). As a corollary, a D-convergent sequence is infinite only if the space is non-T_1 separable, and that an infinite sequence D-converges to a point x_0 if and only if there exists N such that all the points x_n, n=N,N+1,... have higher specialization order (or "finer-grainedness") than x_0. These properties are the counterparts to the well-known property of Cauchy sequences: every infinite C-convergent sequence has a unique limit point if and only if the space is T_2 (i.e., Hausdorff) separable. In this way, while C-convergence models the cognitive metaphor of "approaching" a target point from a sequence of progressively closer but distinct and mutually separated points, D-convergence models the metaphor of "zooming in" onto a target point from a sequence of "fat" points with progressively finer resolutions. They are two different modes of convergence in the dynamic construal of actual sequences, used under different contexts.

An Evidence Accumulation Model of Strategic Choice

Bhatia, Sudeep, and Golman, Russell.

What are the cognitive mechanisms involved in game theoretic decision making? How do decision makers represent reward-interdependencies in strategic games, and how do they deliberate (intelligently, but perhaps imperfectly) about these interdependencies to generate choice? We address these questions using a bidirectional evidence accumulation model. Our model is able to intelligently reason through two-player strategic games, while also generating the specific violations of Nash theory observed in these games. Additionally, the main ingredients of accumulator models, stochastic sampling and time dependence, play a critical role in explaining these violations. Finally, we show that our model subsumes logit quantal response equilibrium and level-k reasoning (and, in turn, pure-strategy Nash equilibrium) as special cases that arise with specific assumptions regarding decision noise and decision time.

An Extended Bayesian Analysis of Recognition Memory

Dennis, Simon, Osth, Adam, and Lee, Michael.

Dennis, Lee and Kinnell (2008) proposed a Bayesian method for analyzing yes/no recognition memory experiments that has several advantages over standard approaches. The technique is able to provide evidence in favor of both the alternate and null hypotheses, can be used iteratively as data becomes available, estimates the proportion of subjects that conform to either the null or alternate hypothesis rather than making inferences about means, is applicable with small sample sizes, adjusts for edge effects in hit and false alarm counts in a principled manner and properly accounts for uncertainty in hit and false alarm rates given counts. In this work, we extend the analysis to apply to confidence rating and forced choice

data and between subjects designs. We demonstrate how one can incorporate uncertainty about the ratio of standard deviations of new and old distributions of memory strength into the model and provide informed priors to improve sensitivity. Using synthetic data we show that the analysis approaches which are typically applied in the area are unreliable and that the new method is more robust.

An IRT forecasting model

Bo, Yuanchao Emily, Budescu, David, Lewis, Charles, Tetlock, Philip, and Mellers, Barbara.

In this paper, we proposed an item response theory (IRT) forecasting model, which incorporates proper scoring rules into item response models of forecasts. We offer a model for evaluating people via proper scoring rules that allows us to account for factors that are difficult to include in simpler Brier scoring rules. By using this IRT forecasting model, we can about learn features of the items. The model also helps with item development and the identification of domains in which items have greater forecasting accuracy. We applied the model to geo-political forecasts from the Good Judgment Project and used the Gibbs sampling algorithm to estimate model parameters. The model and the algorithm tolerated the sparseness of the data set and provided a good fit. The correlation between the ability estimates and Brier scores was high. We discuss the benefits of using item characteristic information in forecasting.

Approximation of Kolmogorov Complexity for Short Strings via Algorithmic Probability

Singmann, Henrik, Gauvrit, Nicolas, Soler-Toscano, Fernando, and Zenil, Hector.

Kolmogorov-Chaitin complexity or algorithmic complexity has long been believed to be impossible to approximate when it comes to short sequences (e.g. of length 5-50). The newly developed coding theorem method allows for the first time to estimate the complexity of strings of length 2-11 via numerical methods. Specifically, the algorithmic probability of a string s, m(s), is defined as the probability that a randomly selected deterministic program (or Turing machine) will produce s and then halt. According to the algorithmic coding theorem the algorithmic complexity is approximated by âĹŠlog(m(s)). We ran large numbers of Turing machines using either 2, 4, 5, 6, or 9 different symbols and recorded their halting states to approximate m(s). The resulting distributions of strings contain all strings of length 2 to 10 and have been made available in a package for the statistical programming language

R called acss. In other words, the acss package provides objective measures of the complexity (or randomness) of all strings of length 2 to 10 with either, 2, 4, 5, 6, or 9 different symbols. In this talk we present the theoretical basis of our method, its relationship to other methods of assessing complexity (i.e., compression), and show how it can be applied to such diverse phenomenon as the representativeness heuristic or the assessment of the working memory span.

Assessing Risky Weighting Functions by Means of their Logarithmic Derivative Function

Chechile, Richard A., and Barch, Daniel H.

A general problem in mathematical psychology is discriminating among many similar nonlinear functions that capture key empirical findings. A common solution to this problem is to employ statistical model comparison statistics (such as the Bayes factor) to select the preferred scientific description. In this paper we demonstrate that this approach can be misleading. An alternative model selection method is to use metrics such as the hazard function, the reverse hazard function, or more generally the logarithmic derivative (LD) function. In this research we examine the LD function of the risky weighting function. In cumulative prospect theory (Tversky & Kahneman, 1992), the probabilities of lottery outcomes are nonlinearly transformed to a risky weighting function in order to handle the Allais (1953) paradox. We show that only one candidate model for the risky weighting function has an LD function that is consistent with the experimental data for both positive and negative lotteries. These results lead to a new interpretation of the role of context for risky choice.

Augmenting Cognitive Models with Neuorphysiology

Turner, Brandon, Van Maanen, Leendert, and Forstmann, Birte.

Behavioral models instantiate cognitive theory by assuming a set of statistical processes that mimic underlying decision dynamics. These processes are latent, meaning that the parameters that regulate them can only be estimated from the behavioral data collected during an experiment. However, basing parameter estimates on behavioral data alone makes relatively uninformed connections to the remarkably fluid process of cognition. In particular, cognitive models rarely employ the machinery required to allow for gradual or temporary changes in an observer's state of mind (e.g., attention). Instead, one typically assumes that decisions fluctuate from trial to trial in an identical, and independent fashion. Such a prediction is warranted if behavioral performance is considered in aggregate form, collapsing

across the trial information, but such a procedure dampens our ability to fully appreciate the dynamics of trial-level decision making.

There now exist methods for assessing an observer's state of mind on a trial-to-trial level through neurophysiological techniques. In this talk, we discuss a method for augmenting behavioral models with neurophysiology. We show in two separate demonstrations – one including EEG and one including fMRI measures – how neurophysiology can be used to describe an observer's state of mind, and how this description can be used to enhance both explanatory power of decision dynamics, and predictive accuracy in a cross-validation test.

Bayesian Induction and Reproducibility

Shiffrin, Richard M., and Chandramouli, Suyog.

There have been many technical advances in recent years concerning methods for scientific induction: These include variants of the principles of Bayesian Model Selection (BMS) and Minimum Description Length that are used to compare models based on our prior beliefs and the current data. In last year's meeting I presented an extension of BMS that infers the probability that a model instance or class provides the best approximation to the true generating distribution. This year's talk simplifies the theory to the point that it can be explained in a single table, without equations. Using the table one can see how to represent our knowledge, carry out induction, compare models, and assess reproducibility.

Bayesian K-INDSCAL for modeling both group characteristics and individual differences in similarity data

Okada, Kensuke, and Lee, Michael.

Perceptual similarity data obtained from multiple subjects may reflect underlying group, as well as individual, differences in processing stimuli. The K-INDSCAL model, which is a mixture of the INDSCAL multidimensional scaling model in K latent groups, has been proposed (Bocci and Vichi, 2011) to capture both group and individual characteristics. However, the existing least-squares approach to estimation does not fully characterize the uncertainty associated with model parameters as well as the model itself. Here, we propose a Bayesian approach for K-INDSCAL to incorporate these uncertainties. Using the Bayesian method we can obtain estimates and their uncertainties for the configuration of stimuli in group spaces, the individual weights given to each dimension of the space, and the membership of subjects to the groups. It also enables us to evaluate the goodness of the model by assessing its predictive performance. The usefulness of the proposed approach is demonstrated by several analyses of similarity ratings datasets.

Bayesian models of cognition revisited: Letting go of optimality and letting data drive psychological theory

Tauber, Sean, Navarro, Daniel, Perfors, Amy, and Steyvers, Mark.

We outline an alternative framework for Bayesian models of cognition (BMCs) which disentangles the apparatus of BMCs (with their use of priors, likelihoods, and hypothesis spaces, all of which we keep) with the claims about rationality (which we eliminate). We relax the requirement that individual humans need to be strictly optimal learners. Under this view, Bayes' rule is viewed solely as a tool for describing the assumptions that underpin a theory about cognition. A prior need not capture the "correct" environmental statistics for some problem; it need only capture some beliefs that the learner might bring to the task. A likelihood need not describe the "true" manner in which observations are generated; it need only describe how the learner thinks they were. The hypotheses considered by the learner need not include the best hypothesis in some objective sense; they need only include some cognitively-plausible set of options a learner might consider. Models in this framework are called DDBMCs (for data-driven Bayesian models of cognition) because we draw inferences about the model directly from human data. This kind of model is given no special "rational" status by virtue of being Bayesian. Instead, it allows us to learn about how background knowledge shapes inductive inferences (by inferring the prior); how tasks and individual differences lead to variability in learning rules (by inferring the likelihoods); and about the mental representation people bring to an inference task (by inferring the hypothesis space). We provide a general overview of the framework as well as several examples.

Bayesian models of latent-strategy learning in dynamic environments

Mistry, Percy K., and Trueblood, Jennifer S.

Strong learning effects have been established in both the information acquisition and decision making processes when the task environment is changes over time. We demonstrate that existing approaches for incorporating such learning effects into multiple-strategy based models where the underlying strategies are latent cognitive processes can be problematic under certain environmental conditions. This is especially so when the information patterns in the task change over time (e.g., switching between compensatory and non-compensatory environments) and when information acquisition patterns are sparse (e.g., in the case of costly information search). We propose an approach that redefines latent heuristic strategies and associated cognitive processes in a probabilistic manner in order to perform Bayesian inference over such latent processes. We demonstrate how Bayesian hierarchical modeling can then be used to model such multiple strategy based approaches with learning effects that govern the

adaptive use of such strategies, for instance, a learning-based adaptive toolbox. Finally, we explore the implications of different learning rate models on such adaptive multiple-strategy models.

Beyond Shannon entropy: a unified mathematical framework for entropy measures and its importance for understanding human active learning

Nelson, Jonathan D., Crupi, Vincenzo, Meder, Bjoern, Cevolani, Gustavo, and Tentori, Katya.

One of the most important kinds of decisions that people make are decisions about which test (or experiment) to conduct next. For instance, in medical diagnosis, a carefully chosen test can helpfully narrow the range of plausible diseases that the patient might have. In a probabilistic framework, test selection can often be predicted with the idea that people have the goal of reducing entropy (uncertainty) in their beliefs about the possible states of the world. For instance, the goal could be to conduct the test that in the expectation will lead to lowest posterior uncertainty (entropy) about the patient's true illness.

In psychology and medical decision making, reduction in Shannon entropy (information gain) is predominant. But a variety of entropy metrics (Hartley, Tsallis, RÃl'nyi, Arimoto, Quadratic) are popular in different fields within the social sciences, the natural sciences, artificial intelligence, and the philosophy of science. Particular entropy metrics have been predominant in particular fields; it is not clear when particular measures' predominance in an individual domain may be due to historical accident.

We show that many entropy and information gain measures arise as special cases in the Sharma-Mittal family of entropy measures. Using mathematical analyses, analysis of earlier human behavioral data, and simulations, we address:

(1) How do these different entropy models relate to each other? What insight can we obtain by considering the individual entropy models within this unified framework?

(2) What is the psychological plausibility of each possible entropy model?

(3) What important new questions for empirical research arise from these analyses, both with human subjects and in applied domains?

Computational Cognitive Neuroscience Modeling of Category Learning in Apathetic Parkinson's Disease Patients

von Meer, Stella Sophia, Valentin, Vivian, Filoteo, J. Vincent, Maddox, W. Todd, and Ashby, F. Gregory.

Parkinson's disease (PD) is a neurodegenerative disease that targets the dopamine neurons in the substantia nigra, which causes a notable dopamine deficiency in the striatum. However, degenerative changes extend beyond the dopaminergic system. Apathy is a neuropsychiatric symptom that affects almost 40% of PD patients. Recent studies suggest that relative to nonapathetic PD patients at the same disease stage, apathetic PD patients have decreased amygdala volumes, and are impaired in nonlinear information-integration (II) category learning, but not in one-dimensional rule-based (RB) category learning. These results are modeled using a computational cognitive neuroscience approach. The amygdala projects to the dopamine neurons in the substantia nigra pars compacta (SNpc). The heaviest of these projections is into regions of the SNpc that project to dorsolateral regions of the striatum that have been hypothesized to mediate II category learning (i.e., by the COVIS model of category learning). A spiking neuron model of the COVIS procedural learning network accounts for the II learning deficit of apathetic PD patients by assuming that the reduced amygdala volume reduces the gain on dopamine release into the dorsolateral striatal compartments that mediate II learning. The model predicts no extra deficit due to apathy on RB category learning because the amygdala projects only weakly to dopamine neurons that target prefrontal cortex (i.e., in the ventral tegmental area).

Contextual Similarity, Attention, and the Invariance Context Theory Model of Categorization

Vigo, Ronaldo

Over the past few years, data from several empirical studies on concept learning difficulty (e.g., Vigo, 2013; Vigo, Zeigler, & Halsey, 2013; Vigo, Evans, & Owens, 2014; Vigo & Doan, 2015) has corroborated predictions made by the Generalized Invariance Structure Theory (GIST; Vigo, 2013, 2014) of concepts with respect to the role that structure plays in determining the degree of concept learning difficulty of categorical stimuli defined over continuous, binary, and n-ary valued dimensions. GIST posits that humans detect invariance patterns in categorical stimuli that are necessary for the formation of rules and prototypes as concept representations. These patterns are encoded as vectors in psychological space (referred to as ideotypes) whose components are the proportion of detected categorical invariants in categorical stimuli. These proportions of categorical invariants characterize the degree of

redundancy/diagnosticity associated with each of the stimulus dimensions. We show that unifying this framework with distance similarity measures, such as the universal law of generalization (Shepard, 1987), generates new similarity measures that, without free parameters, account for the contextual effects that are rooted in the perceived relationships between the dimensional values of objects in categorical stimuli. This new approach to similarity is then used to develop a two-stage process theory and model of categorization named "the invariance context theory model" (ICTM). We demonstrate that, without free parameters, the ICTM accounts accurately for the variance in current and historical categorization data and that it seamlessly unifies the primarily global (i.e., category/concept level) account of concept learning proposed in GIST with the primarily local (i.e., exemplar level) process account of categorization underlying the Generalized Context Model (Nosofsky, 1984, 1986).

Curve detection explained as the shortest path in the visual cortex

Kwon, Tae Kyu, Agrawal, Kunal, and Pizlo, Zygmunt.

Last year we presented a new model for integrating a closed, fragmented contour in a noisy image. The model finds the contour by solving the shortest path problem in a log-polar representation of the image that is known to exist in area V1 of the primate cortex. This model makes strong predictions about the effect of the fixation position, which corresponds to the origin of the polar coordinate system on the retina, on detectability of contours. These predictions were tested in two experiments.

We presented fragmented egg-like shape in a noisy image and asked the subject to discriminate whether it pointed to the left or right. The exposure duration was short (100 ms) to eliminate eye movements. The orientation of each contour fragment in the egg's contour was perturbed so as to minimize spatially-local operations based on smoothness.

In the first experiment, the fixation point was in the center of the egg or on the egg's contour. We used two sizes of the egg and two densities of contour fragments to counterbalance the effect of retinal eccentricity and the number of samples around the egg's contour. Fixation in the center led to discriminability 6 times higher than fixation on the contour. Fixation on the contour produced near-chance performance. These results are consistent with the model's predictions. To further investigate the effect of fixation position inside the egg, the second experiment was conducted by shifting the fixation point gradually from the center to the boundary of the egg. The model and the subjects could discriminate the shape of the egg well when the fixation point was near the center of the curve, and as the fixation point was getting close to the boundary, performance dropped in a similar way. These results provide a strong support for the model.

Diffusion Theory of Decision Making in Continuous Report

Smith, Philip Leigh

I present a diffusion model for decision making in continuous report tasks, in which a continuous, circularly-distributed, stimulus attribute in working memory is matched to a representation of the attribute in the stimulus display. Memory retrieval is modeled as a two-dimensional diffusion process with vector-valued drift on a disk, whose bounding circle represents the decision criterion. The direction and magnitude of the drift vector describe the identity of the stimulus and the quality of its representation in memory, respectively. The point at which the diffusion exits the disk determines the reported value of the attribute and the time to exit the disk determines the decision time. Expressions for the joint distribution of decision times and report outcomes are obtained by means of the Girsanov change-of-measure theorem, which allows the properties of the nonzero-drift diffusion process to be characterized as a function of a Euclidian-distance Bessel process. Predicted report precision is equal to the product of the decision criterion and the drift magnitude and follows a von Mises distribution, in agreement with the treatment of precision in the working memory literature. Trial-to-trial variability in criteria and drift magnitudes lead, respectively, to direct and inverse relationships between report accuracy and decision times, in agreement with, and generalizing, the standard diffusion model of two-choice decisions. The two-dimensional model provides a process account of working memory precision and its relationship with the diffusion model, and a new way to investigate the properties of working memory, via the distributions of decision times.

Discrete-Slots and Variable-Resources Models of Change-Detection Choices and Response Times

Nosofsky, Robert M., and Donkin, Chris.

An ongoing theoretical debate is whether visual working memory (VWM) is better characterized in terms of a discrete-slots system that gives rise to mixed states of memory or in terms of a continuous system that assigns variable resources to the items in memory. The mixed-state view proposes that decisions involving VWM involve a mixture of memory and guessing, whereas there is no true guessing state in the continuous models. However, by making allowance for highly diffuse memory representations, the continuous models can produce behavior that is similar to guessing. In this work we report on various efforts that attempt to decouple the predictions of the mixed-state and variable-resources models of VWM change detection, many of which rely on formal modeling of response times.

Distribution-free Fechnerian Binary Choice

Cavagnaro, Daniel, Regenwetter, Michel, and Popova, Anna.

Fechnerian models state that the pairwise choice probability for a choice between two choice options is a monotonic function of the "decision maker's strength of preference in favor of one option versus the other," with the constraint that the preferred option in any pair has choice probability exceeding one half. This means that the permissible choice probabilities of a Fechnerian model form a union of convex polytopes and can be tested using frequentist and Bayesian order-constrained inference methods. This permits the behavioral economist, decision analyst, psychologist, econometrician, or marketing analyst to abstract away from the structure imposed by some distributional assumptions in a Fechnerian specification, and to evaluate what inferences or predictions can be drawn irrespective of error term distributions. We discuss the special case of strong utility models where "strength of preference" is the arithmetic difference of utility values. These include classic Logit and Probit models.

Duality of similarity- and feature-based learning via kernel methods, with application to selective attention

Jones, Matt, and Zhang, Jun.

The kernel framework from machine learning offers a new perspective on psychological models of learning. In particular, recent work has shown that similarity-based generalization and feature-based association learning can be formally equivalent, provided the set of features bears the right relationship to the similarity function. Rather than treating this as an issue of model identifiability, we suggest viewing it as one of duality: The brain is doing similarity- and feature-based computation simultaneously. The kernel duality can be used to translate between these two modeling frameworks, using principles traditionally expressed in one to generate insights within the other. We illustrate this approach with the example of learned selective attention, showing how two very different theories of attention in learning – grounded in similarity and in cue associability – are complementary instantiations of the same general principle when cast within the kernel framework.

Dynamic accounts of cognitive dissonance findings

Kvam, Peter, and Pleskac, Timothy.

A common finding associated with cognitive dissonance theory is that people tend to prefer an item more strongly if they have chosen it over another (bolstering effect). However, early work on the topic also uncovered instances of the opposite effect, where preference

strength was lower for a chosen item than when no decision was made (suppression effect). Possibly because dissonance theory is neither a dynamic nor a quantitative model, existing empirical work does not provide the precise time control on preference judgments necessary to understand the time course of these effects. Additionally, current models that could be used to account for such a dynamic process (such as decision field theory) are insensitive to choice – instead assuming that a decision is made by simply reading information out of a pre-existing cognitive state – so they do not predict either effect. In order to address each of these issues, we first examined the empirical time course of post-decision preferences in a multi-attribute binary choice and preference rating experiment. By comparing a condition where participants had to choose between items then rate their preference against one in which they only rated their preference, we showed instances of both bolstering and suppression effects resulting from oscillating preferences over time. Second, we developed a quantum random walk variant of decision field theory [DFT], which represents preferences as a superposition over multiple preference levels and treats decision-making as a constructive process by collapsing this state onto the corresponding preference levels when a decision is made. This quantum DFT model predicts a priori both the suppression and bolstering effects as well as oscillations within conditions. In addition, we compared quantum to classical DFT using a grid approximation of the likelihood functions and uniform priors to compute a Bayes factor between the two. This comparison strongly favored quantum DFT, and suggests that it may provide a viable quantitative and dynamic account of pre- and post-decisional preference formation.

Dynamic cognitive models of intertemporal choice

Dai, Junyi, Pleskac, Timothy, and Pachur, Thorsten.

Recent empirical results show that intertemporal choice is probabilistic, dynamic, and attribute-based, challenging traditional models such as the discounted utility model. In this paper, we develop and test three classes of cognitive models that embody these three properties of intertemporal choice. The first model class involves diffusion models built upon decision field theory (Dai & Busemeyer, 2014); the second class is newly developed from principles of lexicographic and limited search; and the third class incorporates traditional concepts of random utility and just-noticeable-difference (JND) to provide novel accounts for the cognitive mechanisms underlying intertemporal choice. We showed that all three model classes provide reasonable predictions on distributions of choice responses and response times, although they differ substantially in underlying assumptions (e.g., compensatory versus noncompensatory strategies and accumulative versus non-accumulative samplings). Qualitatively, these model classes can account for distinct sets of major phenomena in intertemporal choice. Quantitatively, a model built upon the concepts of random utility and JND performs best overall. Yet,

different classes provide best fits for different groups of participants, suggesting individual difference in the underlying process dynamics.

Empirical Evaluation of Third-Generation Prospect Theory

Birnbaum, Michael H.

Third generation prospect theory (Schmidt, Starmer, & Sugden, 2008) is a theory of choices and of judgments of buying and selling prices of risky prospects. Buying and selling prices are also called willingness to pay (WTP) and willingness to accept (WTA). The fact that buying prices exceed selling prices was called the effect of the judge's point of view and later called the endowment effect. Third generation prospect theory combines cumulative prospect theory for risky prospects with the theory that judged values are based on the integration of price paid or price received with the consequences of gambles. This theory was developed independently of previous similar work on the same topic by Birnbaum and Zimmermann (1998) and by Luce (2000). This paper reviews theoretical and empirical findings, some previously unpublished, to show that third-generation prospect theory fails as a descriptive model of both choices and judgments. In particular, it can be shown that the theory implies a property called complementary symmetry, which is that the buying price of a binary gamble plus the selling price of the complementary gamble should be entirely dependent on the total value of the prizes of the gamble, independent of other features of the gamble, such as probability to win and range of consequences. Further, the theory implies that prices should satisfy first order stochastic dominance: if A dominates B, one should not set a higher WTP or WTA for B. The data systematically violate these and other properties and they are better fit by earlier models developed in psychology.

Empirical tests of invariants in the algebraic structure of preference

Davis-Stober, Clintin, Brown, Nicholas, and Cavagnaro, Daniel.

A large empirical literature has established that different individuals often apply different strategies when making a decision. In contrast to approaches that primarily seek to evaluate individual theories, we investigate what aspects of the decision-making process do or do not change across individuals. For example, a group of individuals may each apply different strategies in similar contexts, but all individuals could apply strategies that conform to weakly ordered preferences. We present a general approach for identifying and testing potential invariances in the algebraic structure of preference. We demonstrate how this approach, when used in conjunction with Bayesian order-constrained statistical inference, can be used to

disentangle the response variability of a decision maker's observed choices with the variability of his or her true preferences.

Ensemble Accumulator Models of Choice Decision Making

Miller, Brent J., Zandbelt, Bram, Logan, Gordon D., Schall, Jeffrey S., and Palmeri, Thomas J.

Decision-making is explained by psychologists through stochastic accumulator models and by neurophysiologists through the activity of neurons believed to instantiate these models. As noted recently by Zandbelt et al. (2014), this identification has overlooked an inherent scaling problem, where the same accumulator model is being used to explain behavior as well as explain a neural component giving rise to behavior. Here we extend the examination from Zandbelt et al. to situations involving choice between alternatives. To investigate the scaling from individual accumulators in models of behavior to ensembles of neural accumulators in the brain, we introduce a framework for modeling RT and accuracy in choice that incorporates varying numbers of redundant accumulators for each of two alternatives. We highlight conditions under which individual accumulator RTs, choice, and dynamics are not differentiable from those predicted by the overall ensemble of accumulators. Highlighting conditions under which predicted behavior and accumulator dynamics are invariant with ensemble size promises insights into the likely organization of accumulator-like elements in the brain.

Evaluating the robustness of output interference

Aue, William R., Criss, Amy H., and Wilson, Jack H.

The benefits of testing are well known (e.g., retrieval practice effects), but the encoding that occurs during testing can also harm memory on subsequent test trials. This phenomenon, termed output interference (OI), manifests as a decline in episodic memory performance across single testing session. We employed Bayesian statistical techniques to evaluate the presence of OI across several experiments and memory tasks. In addition to the item memory tasks for which OI has been previously observed, we examined OI for associative tasks (e.g., cued recall), for different types of materials (e.g., factual questions), and at both the aggregate and subject levels of analysis. On the whole, we found that OI was pervasive across episodic memory tasks. Explanations for the susceptibility of episodic memory to the interference generated during testing, and the implications for models of memory, are considered.

Extending the Linear Ballistic Accumulator to the Psychomotor Vigilance Task

Fisher, Christopher, Blaha, Leslie M., Walsh, Matthew, and Gunzelmann, Glenn.

Sequential sampling models have been successful in accounting for reaction time (RT) and choice data from simple decision making tasks with fixed trial structures. Sequential sampling models assume that information is sampled from the stimulus and evidence for each possible response accumulates until a decision threshold is met. The linear ballistic accumulator (LBA) is a parsimonious and mathematically tractable sequential sampling model that assumes evidence for each response alternative is accumulated in an independent, deterministic and linear fashion. We extend the LBA to the psychomotor vigilance task (PVT), a simple RT task in which stimuli are presented at random inter-stimulus intervals ranging between 2 and 10 seconds. The PVT requires sustained attention during the variable inter-stimulus interval and marks a departure from fixed trial structure common to most experiments. A typical finding in the PVT is increased skewness in the RT distribution, false starts (RTs before the stimulus onset) and lapses (RTs $>$ 500 ms) as participants become fatigued. In order to capture the commission of false starts during the inter-stimulus interval, a separate pre-stimulus processing stage is added to the standard stimulus-driven LBA response process. Thus, the extended LBA consists of separate inter-stimulus interval (ISI) and stimulus interval (SI) accumulation process. During the ISI accumulation process, the drift rate is generally negative with a starting point of zero, reflecting random and relatively infrequent false starts. The ISI accumulation process terminates upon the stimulus onset, prompting the initialization of the SI accumulation process. As with the standard LBA, the SI accumulation process includes random starting point variability and a positive drift rate. The ISI and SI accumulation processes share a common decision threshold and non-decision time, resulting in the addition of only one free parameter, the ISI drift rate. We show through simulation that the extended LBA is capable of accounting for the full RT distribution in the PVT, including increased skewness, false starts and lapses due to fatigue.

Falsifying unfalsifiable models - grounding model inputs in stimulus values rather than free parameters

Teodorescu, Andrei Radu, Moran, Rani, and Usher, Marius.

In 2013, two papers were published in Psychological Review pointing out the crucial problem of model mimicry within the sequential sampling model class and its origin in arbitrary technical model assumptions. However, while the work by Jones & Dzhafarov concludes that the entire class is unfalsifiable, the work by Teodorescu & Usher endeavors to provide a frame-

work of theoretically driven experimental design which generates non-overlapping, and thus falsifiable, predictions from different models. How can such opposed conclusions co-exist? In this talk I will try to bridge the two works by discussing the similarities and differences and illustrate the value of emerging insights in a follow up study to Teodorescu & Usher (2013). In sequential sampling decision models, the evidence accumulation process is terminated by a stopping rule which can be applied to the absolute level of activation representing the accumulated evidence for each of the response alternatives. Independent Race and LCA models operate under this assumption. On the other hand, the stopping criterion can also be applied to some function of the relation between the absolute activations. For example, in diffusion models the criterion is applied to the difference while in normalization models it is applied to the ratio. By definition, models implementing relative thresholds are invariant to input manipulations that do not affect the relative aspect of the evidence to which the stopping rule is applied (i.e. difference or ratio). Therefore, a manipulation that only affects the absolute input level without altering its relative aspects could discriminate between relative threshold models, which would predict the null effect, and absolute threshold models, which are sensitive to the overall increase in activation. We present an experimental paradigm which allows for the manipulation of absolute inputs while maintaining constant either their ratio or their difference. The results reveal a surprising sensitivity to the absolute input. While absolute threshold models naturally account for the results, some relative threshold models fail while others require additional assumptions. A revised diffusion model is developed which can account for the data by assuming that the level of internal processing noise is proportional to input strength. Implications for model architectures, model assumptions and different conclusions about the underlying cognitive mechanisms are discussed.

Fast and accurate learning with discrete numerical responses

Sanborn, Adam N., and Beierholm, Ulrik.

Many everyday estimation tasks have an inherently discrete nature, whether counting discrete objects (the number of paint buckets) or estimating discretization of continuous variables (the number of paint buckets needed to paint a room). While Bayesian inference is typically used for modeling human perception and estimation for binary or continuous response problems, task using discrete numerical responses have not been separately investigated, despite their common occurrence in everyday life. Here we use Bayesian decision theory to characterize how people make a discrete numerical response using two tasks: a numerosity and a visual area estimation task. In three experiments, we found that participants use a continuous likelihood distribution and chose one of two decision functions for converting their uncertain representation into a response: either by drawing samples from an exponentiated form of

the posterior distribution or by taking the maximum of their posterior distribution. Little evidence was found for an averaging decision function. Surprisingly, the prior distributions used by participants in our experiments were much more flexible and adaptive than those found in previous research. With continuous responses, participants have required thousands of trials to clearly learn bimodal priors, but our participants were able to discrete bimodal and even discrete quadrimodal priors within a few hundred trials. Participants demonstrated that they can flexibly use combinations of continuous and discrete components to make decisions when it is appropriate.

Fast and easy to use inference methods for Bayesian nonparametric processes

Austerweil, Joseph Larry, and Qian, Ting.

Bayesian nonparametric processes (BNP) are probabilistic models that can capture arbitrarily complex structures, while avoiding overfitting by introducing prior biases towards simpler structures. BNPs (e.g, Dirichlet process and Beta process) have been used successfully to describe human behavior and predict novel phenomena in several domains (e.g., categorization and feature formation). Given their theoretical, descriptive, and predictive strengths, why have only a few researchers adopted these methods for their own modeling purposes? One critical reason is the computational complexity of approximating these models on realistic data sets: It can be difficult to impossible depending on the size and dimensionality of the data.

To make inference with BNP methods feasible for big data sets, we present the Massively Parallel Bayesian Nonparametric Process toolkit (MPBNP), which is an open source, publicly available Python package containing easy-to-use BNP approximation techniques that are implemented in a massively parallel manner and GPU-optimized. GPU optimization provides incredible performance gains. This enables data sets to be analyzed using BNP methods that otherwise would be infeasible. It is optimized using OpenCL, which is architecture independent (unlike CUDA) and allows for major performance gains even on laptops and workstations without powerful GPU cards. Although the toolkit is still in its beginning stages, we will present promising preliminary demonstrations and result, including: greater than 50x speed improvements for the Dirichlet process mixture model on large data sets (compared to the same algorithm written in C optimized to run on a CPU) and the first application of the transformed Indian buffet process to real binary image data sets.

Feature-based attention affects the information accumulation process: An fMRI study

Yu, Ju-Chi, Chen, Der-Yow, Little, Daniel R., and Yang, Cheng-Ta.

Feature-based attention describes the ability to selectively attend to a task-relevant feature while ignoring other task-irrelevant features. Previous fMRI research showed that feature-based attention modulates the cortical activities in the early visual areas (i.e., V1 and V4). However, less is known about how feature-based attention modulates frontal activities, which may be related to information accumulation during decision making. In the present study, response times and BOLD signals were recorded while participants completed a delayed matching task which manipulated the task relevancy of two features (i.e., both color and shape or either color or shape were relevant). The same/different choice RT data was analyzed with the linear ballistic accumulator model (LBA; Brown and Heathcote, 2008) to simulate how featural information is accumulated as a function of task relevancy. Behavioral results showed that the matching performance was affected by the task-irrelevant feature, suggesting that participants were not able to ignore the processing of the task-irrelevant feature. Further, we correlated the estimated drift rate parameters and corresponding BOLD signals. Results showed that the contrast of medial frontal gyrus (MFG) activity was significantly correlated to the drift rate difference between the conditions when both features were relevant and when only color was relevant, suggesting that MFG is related to the information accumulation when attention is drawn to an irrelevant shape. On the other hand, the contrast of superior frontal gyrus (SFG) activity was correlated to the drift rate difference between the conditions when both features were relevant and when only shape was relevant, suggesting that SFG is related to the information accumulation when attention is drawn to an irrelevant color. In addition, using a logistic regression model to fit the drift rate parameters, results showed significant correlations between the contrasts of anterior cingulate cortex (ACC) activity and the estimated logistic parameters for the task-irrelevant feature. Together, our results supported that both features are processed regardless of task relevance. Feature-based attention can modulate the information accumulation process, and the modulation is correlated to the activities in the frontal cortex.

Flexibility in Evidence Accumulation Model Estimation

Heathcote, Andrew, Gretton, Matthew, and Voss, Andreas.

Evidence accumulation theories are often put forward as one of the most successful types of cognitive model. Recently Jones and Dzhafarov (2014) showed that removing an restraint on the form of trial-to-trial distributions and relaxing selective-influence assumptions allowed

two such widely applied exemplars, Ratcliff's diffusion model (e.g., Ratcliff & Rouder, 1998) and the Linear Ballistic Accumulator model (LBA, Brown & Heathcote, 2008) to fit any pattern of data, and called for a greater focus for on the role of distributional and selective influence assumptions. We investigate the flexibility of recently popular Bayesian methods that seek to estimate the diffusion model with trial-to-trial variability implemented in a hierarchical structure (Vandekerckhove, Tuerlinckx & Lee, 2011) and provide an alternative implementation of the hierarchical Bayesian approach. For the Ratcliff diffusion model this implementation in R calculates likelihoods by numerically integrating out trial-to-trial variability (in C), so that estimates better correspond to the model's normal rate and uniform start point trial-to-trial variability assumptions.

Forty years of random walking

Link, Stephen

The initial application of the random walk ideas to psychological processes probably belongs to Bill Estes' works on learning theory. The general application of sequential processes to discriminative performance came from my laboratory and the works of Burt Tindall, David Ascher, and Rachel Heath. My purpose in this talk is to set the stage for the developments that followed by describing the situation at the time, my discovery of the unneeded assumption in the Einstein, Weiner and Wald approaches, and the subsequent development in psychophysics. After the publication of the original papers by Link and Heath (1975) and Link (1975) others began applications of the ideas in their fields of inquiry. Following these up to today shows how the idea transformed research in psychophysics, memory, and neurophysiology.

Generative and discriminative classification of categorization strategies

Kalish, Michael, and Stephens, Rachel.

Estimation of the effects of individual differences and experimental manipulations on categorization depends on accurate evaluation of the influences of stimulus properties on categorization judgments. These influences can be colloquially characterized in terms of response strategies, and formalized with either generative models (e.g., a naive Bayes classifier) or discriminative models (e.g. logistic regression). Both of these model types can be placed in a hierarchical Bayesian model framework. We consider the precision provided by both model classes when estimating response probabilities across a number of different experiments with multiple tasks per participant.

Hierarchical Bayesian Modeling of Item-Level Effects Item and Associative Memory

Cox, Gregory E., and Criss, Amy H.

Although verbal stimuli are ubiquitous in the study of memory, words vary along a variety of continuous dimensions that are known to have important effects on episodic memory. It is, therefore, critical to the study of memory that the effects of each of these dimensions be suitably characterized. Using a large dataset in which 372 participants performed both single item and associative recognition, we estimated the bias (tendency to call a word "old") and discriminability (ability to distinguish when a given word had been studied or not) of each of the 924 words used as stimuli via a hierarchical Bayesian signal-detection model. Within the same model, we simultaneously estimated the probability that item information would be used in addition to associative information in associative recognition, finding that item information influences associative recognition decisions on average 60% of the time. In particular, it is possible to fail to recognize an intact pair or to correctly reject a rearranged pair if one or both of the items fails to be recognized. Implications for models of memory will be discussed.

How many processes underlie inductive and deductive reasoning?: A high-dimensional state-trace analysis

Stephens, Rachel, Dunn, John, and Hayes, Brett K.

An ongoing debate in reasoning research is whether inductive reasoning and deductive reasoning can be better accounted for by single-process or dual-process theories. Single-process accounts assert that people apply the same cognitive mechanisms to problems of induction and deduction, such as reasoning based on a single scale of evidence for argument strength. Dual-process accounts propose that separate processes, such as heuristic and analytic processes, contribute to reasoning. We present a test of these two accounts by appropriately extending the logic of state-trace analysis. We show how high-dimensional state-trace analysis can be used to identify the latent dimensionality of inductive and deductive judgments. We perform a meta-analysis on existing research that has investigated people's inductive and deductive judgments for logically valid and invalid arguments. We look for data patterns that would lead to the rejection of a single-process account, supporting the need for a multiple-processes account. We find limited evidence of such data patterns. Close examination of the collated data from the meta-analysis reveals distinct clusters of responses for different kinds of arguments. We discuss how these clusters can be used to guide future research into differentiating the competing accounts of reasoning.

Human behavior in contextual multi-armed bandit problems

Stojic, Hrvoje, Analytis, Pantelis, and Speekenbrink, Maarten.

Reinforcement learning (RL) models are often used to study human learning and decision-making. However, they have been rarely employed in decision environments with alternatives characterized by multiple features. Once the function that relates the features to their expected values has been learned, it can be used to generalize beyond the experienced alternatives, to predict the values of new alternatives. Since choice sets regularly change in the real world, we hypothesize that people engage in function learning and that this process interacts with decision-making. We designed a novel contextual multi-armed bandit (CMAB) task where decision makers chose repeatedly between multiple alternatives characterized by two informative features and received outcome feedback on their choices. The values of the alternatives were governed by a noisy linear feature function. In the training session the task was to choose between 20 alternatives for 100 trials with the goal of maximizing long-run reward. We contrasted the CMAB task with classic multi-armed bandit (MAB) version where features were not visually displayed. The CMAB condition had an additional extrapolation test phase with 60 trials, where in each trial three new alternatives were shown. Alternative values were still guided by the same function and participants had to choose one of them without feedback. Behavioral analysis showed that participants in the CMAB used the feature information to direct their exploration for promising alternatives. On average they earned larger rewards and they sampled the alternatives with the highest values more often. In the extrapolation test phase they chose more often alternatives with high function value - indicating that they learned the function. To capture both functional and direct experiential learning we designed a novel function learning based RL model and compared it against classic RL models. This new model clearly outperformed the classic RL model in the extrapolation test phase.

Improving the efficiency of estimating stop-signal reaction time distributions via Bayesian adaptive experimentation

Kim, Woojae, Pitt, Mark, and Myung, Jay.

Response inhibition, or the ability to stop an ongoing process that is no longer appropriate, can be studied using the stop-signal paradigm. Following the modeling framework by Logan (1981), the distributional characteristics of stop-signal reaction times (SSRTs), which are otherwise unobservable, have been measured and studied extensively for the purpose of scientific inquiry as well as clinical diagnoses. Characterizing the distribution of SSRTs for a given participant requires a relatively large number of trials (e.g., the total of go and stop-

signal trials > 500) even with the most efficient methods available so far: The staircased mean method to estimate a mean SSRT (Logan & Cowan, 1984) or the Bayesian parametric estimation to infer the mean and variance of an SSRT distribution (Matzke et al., 2013). This requirement can be burdensome (e.g., testing children, elderly or in a clinic, where time and resources are limited). Addressing the challenge, in the present study, we explored the advantage of Bayesian adaptive methods in estimating SSRT distributions. Simulation studies demonstrate that the number of trials required to obtain estimates of SSRT means and variances with reasonable precision can be reduced considerably with this adaptive method. The results also suggest what conditions concerning the experimental design (e.g., proportion of stop-signal trials) or the underlying parameters (e.g., large vs. small variance) can benefit most from the method.

Learning how to decide: strategy selection and the categorization of environments

Stojic, Hrvoje, Olsson, Henrik, and Speekenbrink, Maarten.

How do people decide how to decide in a given situation? Previous research has indicated that people may solve this strategy selection problem: with time they learn which strategy is more appropriate for a given environment. However, in the real world people are confronted with many environments and have to associate an appropriate decision strategy with each and shift between these accordingly. This aspect of the strategy selection problem - categorization of environments and strategy switching - has not yet been directly examined. Here, we investigate strategy selection learning with environments that are easy to distinguish. If people have difficulty associating strategies to environments in this simple case, it is unlikely they would fare well in more realistic situations where the distinguishing features of environments might not be readily observable. In the training phase of our experiment, participants made pairwise choices between multiple-cue alternatives and received outcome feedback. There were two perceptually different environments, interleaved across trials. In the EB environment, employing an exemplar-based (EB) strategy was more appropriate than a cue-based (CB) strategy, while the opposite was true in the CB environment. In the test phase, participants faced the same environments, but did not receive outcome feedback. Using computational modelling, we found that a large proportion of the participants learned to use a CB strategy in the CB environment and an EB strategy in the EB environment. Most of the remaining participants used the EB strategy in both environments. The experiment shows that people can, on a trial-by-trial basis, adaptively switch between using an EB and CB strategy when these are appropriate. As far as we know, this study is the first to show that people successfully solve the strategy selection learning problem and associate with and apply appropriate strategies to different environments.

Learning to Socially Learn: A Neural Network Model

Whalen, Andrew, Cownden, Daniel, and Laland, Kevin.

Social learning is an active area of research in comparative psychology; many animals, including humans, use social information to better exploit complex environments. Previous theoretical models of social learning in animals have examined social learning at the level of populations, using evolutionary models. In these models, an individual's learning strategy is genetically determined, and allowed to evolve following competition and selection. In contrast, recent experimental evidence suggests that how animals use social information is itself learned.

Here, we present a theoretical model to examine how individuals might use simple reinforcement learning mechanisms to learn how to use social information. We present artificial agents with a foraging task in a complex spatial environment, containing food objects, conspecifics, and distractor objects. We assume that individuals use Temporal Difference Learning, a widely applicable model of reinforcement learning, to learn how to parse and interact with their environment. Our goal is to examine under what conditions individuals learn to use social information and how they process that information.

We find that if individuals are able to easily see food objects, and so do not need social information to forage for food, then they are not influenced by the presence of conspecifics. However if food objects are only visible to nearby individuals, then individuals are able to learn to use conspecifics as a cue for the location of food objects. Furthermore, we find that when individuals are given multiple demonstrators, or demonstrators of varying reliability, they're behaviors are consistent with two experimentally supported learning strategies, "copy the successful" or "majority biased copying".

This work suggests that an animal's social learning ability need not be genetically determined, but may be the product of simple asocial, associative learning. By constructing a theoretical model, we are able to understand under what developmental conditions individuals may learn to use social information, highlighting the role that development may play in shaping the use of social information. Although this work uses a simple model of associative learning, which likely captures the learning in cognitively constrained animals, the flexibility of social information use implied by this model also likely applies to humans and more cognitively complex animals.

Measuring Cognitive Variables Using a Hidden Markov Model

Alexander, Gregory E., and Batchelder, William H.

We build upon an earlier Hidden Markov Model of repeated trial free recall, followed by delayed recall, by incorporating several advances in memory theory. The model has short-term (STM) and long-term (LTM) episodic memory states. In particular, we allow transitions to LTM after successful recall in STM (the testing effect), and we allow retrieval parameters in LTM to fluctuate stochastically as a function of previous recall performance in that state. Thus the corresponding LTM retrieval probabilities allow for monitoring the maintenance of memory as a function of previous successful performance. In addition, the model is specified so that the transition and retrieval parameters may not be homogeneous over repeated study and test trials. Finally, we expand the model to account for heterogeneity in groups by using hierarchical Bayesian inference. By augmenting the model to include hierarchical assumptions and adopting the Bayesian statistical inference framework we increase its applicability for memory related assessment. By specifying our model to match memory theoretic assumptions, we create a cognitive psychometric model whose application gives more interpretable measurements of the latent processes that are affected in memory related impairments. The model is applied to data from healthy elderly and those afflicted in the early stages of Alzheimer's disease.

Model Comparison of Individual Differences in Context Effects

Liew, Shi Xian, Howe, Piers D. L., and Little, Daniel R.

Classical utility theories of decision making have been challenged by the presence of context effects which show that choice probabilities are not only dependent on an option's utility, but also its context in relation to other options. These effects are typically demonstrated by averaging the results of choice tasks across a number of people as well as across a number of different configurations. However, this process of averaging rests on the assumption that no significant qualitative differences exist across people and configurations. We conducted two context effect experiments : one employing an inference paradigm and another with a consumer product paradigm. Both revealed significant qualitative differences across both people and configurations. To this data we fit two sophisticated sequential sampling models: the Associative Accumulator Model (Bhatia, 2013) and the Multiattribute Linear Ballistic Accumulator (Trueblood, Brown & Heathcote, 2014). The fit of both models varied considerably and the implications of this are discussed.

Modeling Decision Processes on Continuous Response Scales

Ratcliff, Roger

I present a model of perceptual decision making for stimuli and responses in continuous space along a line. The model produces predictions for the full distributions of response times and choice probabilities. It is fit to data from experiments in which subjects are asked to make eye movements or finger movements to the brightest part of a display or to the location of the color of a central stimulus on a color wheel surrounding a central stimulus. In the model, continuously distributed evidence from a stimulus drives a continuously distributed noisy decision process that accumulates evidence over time to a decision criterion (a line). The process hits the criterion at a point on the decision criterion line and a response is produced to that point on the line.

Modeling the Time Course of Errors in Long-Term Episodic Memory for Color

Hemmer, Pernille, and Persaud, Kimele.

Bayesian models of cognition assume that prior knowledge about the world influences judgments. For example, prior knowledge influences recall when episodic information is noisy. Recent approaches, however, have suggested that the loss of fidelity from working to long-term (LT) memory is due to an increased rate of guessing (e.g. Brady et al. 2013). This is evidenced by the decreasing precision of information from perception, through working memory and into LT memory. Importantly, the error distributions are well fit by a mixture of a Gaussian-like and uniform distribution; that is, recall is the result of either remembering (with some noise) or guessing. This stands in contrast to the Bayesian cognitive model assumption that recall is a combination of expectations learned from the environment with noisy memory representations. Here, we evaluate the time course of fidelity in LT episodic memory, and the relative contribution of prior knowledge and guessing, in a series of experiments quantifying people's prior expectations and free recall of color. Using a continuous recall paradigm, we found that free recall for color was biased towards the mean hue value for each of seven preferred universal color categories. At an aggregate level performance in the color memory task appears to have a high rate of guessing. However, when partition by lag (i.e., the number of intervening trials between study and test) we found that, immediate LT memory mirrors perception in its high fidelity, but with increasing lag the intermediate precision of appears to be more complex, and at longer lags recall appears to be a mixture of episodic information, and guessing. This is consistent with model based evidence from visual short term memory positing three discrete states of memory: One, a state based on perceptual memory and high precision, two, following the sudden death decay from perception, a state

with intermediate precision based on verbal labeling, and three guessing (Donkin, Nosofsky, Gold and Shiffrin, 2014). We speculate that performance at intermediate lags, consistent with the Bayesian assumption, reflects the influence of category knowledge on noisy episodic representations. We implement and compare several models, including a simple Bayesian memory model and the âĂŸremember-guess' model. We evaluate these models against the data and find that at intermediate lags, the Bayesian model provides a better fit.

Modeling the quality of comments from forecasters in a geopolitical tournament

Chen, Eva, Bo, Yuanchao Emily, Mellers, Barbara, and Tetlock, Philip.

In a geo-political forecasting tournament, participants make predictions on international events, e.g., "Will a country in the European union withdraw membership before December 31st, 2015?" Along with their probabilistic estimates, the forecasters provide comments that can vary from 5 to 500 words. To assess the quality of these comments, we propose a new aggregation algorithm to combine/score ratings. On the forecasting platform, there is one group of forecasters (Group 1, n=2,100) who make probabilistic estimates and provide comments on events of their interest, and then their comments are displayed to another group of forecasters (Group 2, n=3,000) who also make predictions to the same events, of their choosing, and rate the usefulness of comments from Group 1. There is little repeat of the interaction between a particular comment writer and rater. With an average of around 300 comments per day, the challenge is to provide a fair and accurate rating score that goes beyond computing the mean ratings given to a comment by the members of Group 2. We propose to weight the ratings differently based on the characteristics of the forecasters, raters and comments. Therefore, the comments' score derived from a rater(s) must be independent of those who are used in the judging process to insure that there is consistent assessment of the quality of the comments and a valid inference of the forecasters' ability.

Our model is adapted from the many facets Rasch Model (Linacre, 1989), which facilitates the observation and the calibration of differences in rater severity making it possible to account for the differences in the interpretation of the assigned rating. The evaluation of a performance task is related to a number of aspects of the performance setting itself, which are the ability of the forecaster, difficulty of the performance task (i.e., comments to be rated) and characteristics of the raters themselves (i.e., rater severity). Markov Chain Monte Carlo (MCMC) estimation algorithm is used to estimate the model parameters. The model can estimate its parameters in a data set with 85% of missing data. The scores based on our model have a correlation value of 0.75 with the mean approach. For benchmarking quality, the correlation of our model with the length of the comments is greater than the mean approach. The forecasters' rating scores based on our model also have higher correlation

with the forecasters' ability estimates than the mean approach.

Modeling the wandering mind: Informing sequential sampling models with neural data

Hawkins, Guy E., Mittner, Matthias, Boekel, Wouter, Heathcote, Andrew, and Forstmann, Birte.

People often "mind wander" during everyday tasks, temporarily losing track of time, place, or current task goals. Such lapses of attention are particularly likely during repetitive tasks, including psychological experiments. On the basis of behavioral data alone, such as choices and response times, reliably identifying latent task-related or mind-wandering states can be difficult or near impossible. Here, we consider mind wandering as a neural state or process that affects the parameters of cognitive models, which in turn affects observed behavioral performance. Through the lens of cognitive models of speeded decision-making, we consider two approaches that use neural data to constrain cognitive models which in turn help to identify when people mind wander and the effect it has on task performance. The first approach assumes that observed performance arises from a discrete mixture of latent on-task and off-task states. The second approach regresses single-trial measures of neural activity onto structured trial-by-trial variation in the parameters of cognitive models. We contrast the two approaches, and the questions they can answer, and highlight that both approaches allow neural data to provide additional constraints on the parameters of cognitive models, providing a more precise account of the effect of mind wandering on behavior. We demonstrate the approaches with an application to data from a perceptual decision-making experiment using EEG and thought sampling methods to monitor mind wandering during task completion.

Multi-attribute utility models as cognitive search engines

Analytis, Pantelis, Kothiyal, Amit, and Katsikopoulos, Konstantinos.

Multi-attribute utility models as cognitive search engines

In optimal stopping problems, decision makers are assumed to search randomly to learn the utility of alternatives; in contrast, in one-shot multi-attribute utility optimization, decision makers are assumed to possess perfect knowledge of utilities. We point out that these two contexts represent the boundaries of a continuum, of which the middle remains uncharted: How should people search intelligently when they possess imperfect information about the alternatives? In this contribution we show that multi-attribute utility models can guide the search process. In essence, the utility models play the role of cognitive search engines, generating the order in which alternatives should be sampled.

We assume that decision makers first estimate the utility of each available alternative and then search the alternatives in order of their estimated utility until expected benefits are outweighed by search costs. We considered three well-known models for estimating utility: (i) a linear multi-attribute model, (ii) equal weighting of attributes, and (iii) a single-attribute heuristic. We used 12 real-world data sets, ranging from consumer choice to industrial experimentation, to measure the performance of the three models. In simulations, we fixed the attribute weights and the error term corresponding to each model in half of the data set (training set). Then we evaluated the performance of the models in the search task in the remaining half (test set).

On average, linear multi-attribute utility performed best while it searched fewer alternatives. Yet, as in previous model comparisons, in one-shot choice and inference problems we found that heuristic linear models performed close to multi-attribute utility. Moreover, in individual environments the heuristic models often outperformed the full model. To further understand when we should expect heuristic models to outperform the full linear model we examined the relationship between the search problem and the well-studied binary choice problem. We found that in most cases the models that performed well on the binary choice task also did so in the search task. This suggests that previous findings on the ecological rationality of choice and inference strategies are also relevant to the search task.

Multi-dimensional Hilbert Space Modeling of tables extracted from big data

Busemeyer, Jerome, and Wang, Joyce.

When large data sets are collected from different contexts or conditions, often they can be summarized by contingency tables or cross-tabulation tables. Suppose there are K data tables (T1,...,Tk,...TK), each collected under a different context or condition k. Also suppose that each table Tk is a joint frequency table based on a subset of a total of p variables (Y1, ..., Yp). How to integrate and synthesize these K tables into a compressed, coherent, and interpretable representation? Currently, a common solution is to try to construct a p-way joint probability distribution to reproduce the frequency data observed in the K tables. Unfortunately, however, in many cases, no such p-way joint distribution exists that can reproduce the observed tables. This occurs because the data tables violate consistency constraints required by standard (Kolmogorov) probability theory. We present a new Hilbert space multi-dimensional model that is based on quantum probability theory. It provides a promising solution to these problems faced by complex and massive data by constructing a single finite state vector that lies within a low dimensional Hilbert space, and by forming a set of non-commuting measurement operators that represent the p measurements.

Neurally tracking evidence accumulation in similarity-based decisions

van Vugt, Marieke K., and Beulen, Marijke.

Evidence accumulation models such as the drift diffusion model have been very popular in neuroscience to explain how people make decisions and track decision evidence over time.

Most work on the neural correlates of perceptual decision making has been done on experiments with either random dot stimuli or face-car morphs. It is not clear how those generalize to other decisions, in particular those relying on memory. We developed a task in which we could precisely track the amount of evidence for memory (old/new) and perceptual (same-different) decisions about face stimuli from a known similarity space, using theories of summed similarity. We then used classifiers to examine in what intracranial EEG electrodes recorded from epilepsy patients similarity evidence was present over the course of the decision. Our classifiers uncovered a gradually increasing process that differed in its dynamics between individual patients, consistent with theories of evidence accumulation. As such, model-based neuroscience can help us to understand how evidence accumulation may generalize to memory-based decisions.

New Perspectives for Old Recognition Memory Processes

Moran, Rani, and Goshen-Gottstein, Yonatan.

According to dual-process models of memory, recognition is subserved by two processes: recollection and familiarity. Many variants of these models assume that recollection and familiarity make stochastically independent contributions to performance in recognition tasks and that the variance of the familiarity signal is equal for targets and for lures. Here, we challenge these 'common-currency' assumptions. Using a model-comparison approach, featuring the Continuous Dual Process (CDP; Wixted & Mickes, 2010) model as the protagonist, we show that when these assumptions are relaxed, the model's fits to individual participants' data improve. Furthermore, our analyses reveal that across items, recollection and familiarity show a positive correlation. Interestingly, this across-items correlation was dissociated from an across-participants correlation between the sensitivities of these processes. We also find that the familiarity signal is significantly more variable for targets than for lures. One striking theoretical implication of these findings is that familiarity—rather than recollection, as most models assume—may be the main contributor responsible for one of the most influential findings of recognition memory, that of subunit zROC slopes. Additionally, we show that erroneously adopting the common-currency assumptions, introduces severe biases to estimates of recollection and familiarity.

Opportunity cost and reward rate maximization

Khodadadi, Arash, Fakhari, Pegah, and Townsend, James T.

In many real life situations the animals face the problem of how much time they should spend on a decision. By deliberating more on each decision, the accuracy increases. However, if the total time for making a number of decisions is limited, by spending more time on one decision less remains for other decisions. Recently, we proposed a theoretical and experimental framework for investigating the behavior of a rational agent in such situations (Khodadadi, Fakhari and Busemeyer, 2014). Each session of the proposed experiment consists of a number of blocks with fixed duration (for example one minute). The number of trials in a block depends on the time that the subject spends on average on each trial. Crucially, each trial can come from one of the several possible "conditions". A condition specifies the difficulty of the trial, the reward, the penalty and so on. A cue associated with each condition is presented at the beginning of each trial. We showed that to maximize the expected reward during a block, the subject should set a separate value of decision threshold for each condition.

The aim of the current study is to investigate the predictions of the proposed computational framework. Specifically, we conducted an experiment in which there are two conditions: easy condition with high stimulus salience, and hard condition with low stimulus salience. Crucially, the pay-off in the hard condition is +-1 while it is +-20 for the easy condition. The optimal strategy in this experiment is to choose a very low decision threshold for the hard condition and large decision threshold for the easy condition. We fitted two models to the data of each participant: (1) a full-diffusion model with two separate decision thresholds for the two conditions and, (2) a full-diffusion model with the same value of the decision threshold for the two conditions. Surprisingly, the model comparison results show that most of the participants set the same decision threshold for both conditions.

Our Multifractal World: Evidence from Human Decision Making and Activity Monitoring

Heath, Rachel Ann

Multifractals represent complex multiplicative fluctuations that occur on more than one time-scale. They are extant in the physical world as turbulence, and increasingly emerging as important for bodily functions including the heart and the brain, and more recently as a possible representation of complex human cognition. In this talk I will outline the basic features of multifractals and describe a computational procedure, Multifractal Detrended Fluctuation Analysis, from which can be obtained two important indices, the multifractal spectrum's peak location and width, these being measures of persistence and complexity, re-

spectively. Practical applications reveal a decrease in multifractal width in choice tasks that impose time-constraints, and during the long-term activity monitoring of a person diagnosed with Bipolar Disorder I. In both cases, surrogate series are used to control for processes unrelated to multifractality and to provide confidence bounds for establishing its presence in time series data. The theoretical implications of this work are profound. Multifractal response time (RT) series challenge current models of choice decision-making by requiring a representation of between-trial RT fluctuations in terms of multiplicatively interacting processes that imply power-law RT distributions with theoretically undefined variance. Multifractal analyses of activity measures obtained from mobile lifestyle monitoring devices offer new methods for assessing the progress of people with a chronic mental illness such as depression and bipolar disorder.

Quantum Probability Model of "Zero-Sum" Beliefs

Smithson, Michael, and Shou, Yiyun.

Zero-sum statements have a form such as "The more of resource X for consumer A, the less of resource Y for consumer B". These statements have four permutations, and a strict zero-sum believer should regard these four statements as equally valid and therefore should endorse them equally. The measurement of zero-sum beliefs has not received much systematic attention. This paper focuses on the question of whether the endorsement of a zero-sum proposition depends on how the proposition is formed. Across three studies, with adult samples representative of populations in two Western and two non-Western cultures, we find that three asymmetric patterns routinely occur in people's endorsement levels, whereby endorsement of one permutation substantially differs from endorsement of another. The patterns seem to arise from beliefs about asymmetric resource flows and power relations between rival consumers. We apply quantum probability framework to explain the nature of these beliefs. We discuss their implications for the measurement of zero-sum thinking as well as theoretical developments in understanding its causes.

Random utility without regularity

Regenwetter, Michel, and Muller-Trede, Johannes.

Common scholarly wisdom states that random utility models require a consistency property called regularity. According to regularity, a decision maker is more likely to choose a given option x from a given set X of available options than from any larger set Y that contains X. Scholars have used evidence for empirical violations of regularity to question the empirical validity of the general class of random utility models and random preference models.

While regularity is forced by the way modelers in economics, management science, marketing, psychology, and other disciplines routinely state their models, this is not necessary. Random utility and corresponding random preference models can violate regularity, be highly context-dependent, and, yet, be highly parsimonious. Distribution-free random utility models with or without regularity, context-dependent or context-independent, and their associated random preference models, form convex polytopes that are empirically testable with contemporary order-constrained inference methods.

Re-assessing the evidence for exponential and power laws of practice through updated methods of model selection

Evans, Nathan, Mewhort, Douglas, Heathcote, Andrew, and Brown, Scout.

The identity of the non-linear function that governs the rate of decrease in reaction time (RT) over practice has been the subject of debate, with many studies contending for a power rate of RT decrease. However, Heathcote, Brown and Mewhort (HBM; 2000) disputed the findings of these studies due to the averaging of data over participants, and found the exponential function to better fit unaveraged RT data across 17 datasets. Though HBM improved upon the methods used in previous studies, their findings were based purely on goodness-of-fit; a method that has come under scrutiny for failing to account for issues such as model complexity and mimicry. Our study re-analysed the datasets used in HBM to more accurately assess the evidence for the power and exponential functions, using Cross-validation to account for functional-form complexity, and the Parametric Bootstrap Cross-fitting Method to account for mimicry. Although the preference for the exponential function remained for many datasets, there was a shift towards ambiguity or even the power function in some datasets, showing that the exponential function may not necessarily be the function governing RT decrease over practice in all tasks, and the importance of accounting for model complexity and mimicry in model selection.

Re-planning in an unknown stochastic environment

Fakhari, Pegah, Khodadadi, Arash, and Busemeyer, Jerome.

There are many situations in our life that we plan to do something and because of some accidents we have to change to another plan (e.g. you might plan to go to university, then find a job and settle down but a sudden death of your parents makes you the only person who should take care of your younger siblings. Thus your new plan might be to take care of your family and find a job). Most of these situations can't be controlled in a laboratory designed experiments, but navigation in mazes provides this opportunity to study human/animal

behavior and interestingly reinforcement learning (RL) theory found to be a good candidate for this analysis.

In our experiment, we asked our participants to navigate through an unknown maze (find the optimal path) in few moves as possible while maximizing his reward (subjects were told that their payment is based on their performance). Then in the test phase we blocked the optimal path and test whether our participants select the second optimal path or not (detour task), [1].

We found that in the learning phase, all of our participants except one found the optimal path. Also in the test phase in which the participants were supposed to find the second optimal path, 22 out of 29 participants found the correct second optimal path, 6 chose the third optimal path and one who didn't actually perform optimally in the learning phase, didn't choose the optimal path (p-value > 0.05). Our result shows that not only people could find the optimal path; they also could re-plan in case of any changes in the environment.

We applied two RL models to analyze human behavior (learning and choice) in our task. The goal of RL algorithm is to learn a policy that maximizes the future discounted expected rewards [2] by experiencing the environment. The essence of model-free RL is in employing the difference between the actual reward and the estimated reward to update the estimation of action-state pairs locally (model-free RL). On the other hand, model-based RL learns the model (map) of the task (environment) to compute the value of each action. Thus any changes in the environment would be automatically considered in estimating action values and choices. We found that model-based RL could provide a better account of the data.

[1] Tolman, E.C., Honzik, C.H., (1930). Insight in rats. University of California Publications in Psychology 4, 215–232.

[2] Sutton, R. S. & Barto, A. G.(1998) Reinforcement learning. Cambridge, MA: MIT press

Reliance on Small Samples, the Wavy Recency Effect, and Similarity-based Learning

Plonsky, Ori, Teodorescu, Kinneret, and Erev, Ido.

Many behavioral phenomena, including underweighting of rare events and probability matching, can be the product of a tendency to rely on small samples of experiences. Why would small samples be used, and which experiences are likely to be included in these samples? Popular learning models assume reliance on the most recent experiences due to cognitive limitations and/or adaptation to gradually changing environments. We explore a very different and more cognitively demanding process explaining the tendency to rely on small samples: exploitation of environmental regularities. In the first part we study spaces of dy-

namic binary choice tasks, in which the states of nature are either determined by stationary Markov chains or by stochastic autoregressive processes. Computational analyses show that across these wide classes of environments, focusing only on experiences that followed the same sequence of outcomes preceding the current task is more effective than focusing on the most recent experiences.

The second part of our study examines the psychological significance of these sequence-based models. It is focused on the contradicting predictions of popular learning models and sequence-based models. Most learning models predict that the impact of each outcome will be maximal immediately after its occurrence, and will diminish monotonically with time (positive recency). In contrast, sequence-based rules predict a non-monotonic development over time with three distinct stages: The initial effect is negative, then it becomes positive, and finally, in the long term, the effect diminishes. Analysis of published data supports this non-trivial wavy recency pattern and shows robust sequential dependencies ignored by previous research. For example, the tendency to underweight a rare event is found to be strongest three trials after its occurrence. Thus, despite their cognitive cost, sequence-based models have appealing descriptive value.

Implications to similarity-based learning and learning models in general are discussed.

Replication Bayes Factors

Ly, Alexander, Marsman, Maarten, Epskamp, Sacha, Matzke, Dora, Selker, Ravi, Gronau, Quentin, Jamil, Tahira, Steingroever, Helen, Love, Jonathon, and Wagenmakers, Eric-Jan.

The Reproducibility Project: Psychology of the Open Science Framework aims to assess the replicability of research findings in psychology. This large-scale project involves over 150 scientists from around the world who are attempting to reproduce the findings from approximately one hundred studies published in JEP:LMC, JPSP, and Psychological Science. Comparing results from the Reproducibility Project with those from the original studies is a complex undertaking and requires an analysis that connects the original findings to the data observed from the replication attempt. By framing the problem in a Bayesian context one naturally ends up with the Replication Bayes factor. The Replication Bayes factor is constructed from a prior that summarises the original research findings. This prior not only incorporates the effect found in the original study, but it also takes into account the precision with which the effect was measured. By taking the uncertainties of the original and the replication attempt into account, the Replication Bayes factor leads to a fair comparison between the two studies. We extend the work of Verhagen and Wagenmakers (2014) to other common designs and show how the Replication Bayes factor leads to intuitive conclusions

about the replication attempt. Moreover, the analyses are incorporated in the free and open-source statistical software package JASP, and allows readers to reproduce the analyses and results that are discussed.

Representing the dynamics of rating evaluations: A functional approach

Lombardi, Luigi, and Calcagnì, Antonio.

Rating scales (such as, Likert scales, Guttman scales, Feelings thermometers, etc.) represent simple tools for measuring attitudes, judgements and subjective preferences in human rating contexts. Unfortunately, the observed final rating response captures only the outcome of the rating process while the real-time cognitive dynamics that occur during this process are lost. In particular, the usual observable measures generated during a rating task, the final discrete response and eventually its associated response time, are simply end products of the underlying process of rating, not online measurements of it. However, understanding how mental representations unfold in time during the performance of a rating task could be of relevant interest for many researchers working in different empirical domains. Moreover, parsing a rating task into a sequence of subcomponents can help in constructing more sensible indices to detect effects which would otherwise be missed using the standard overall performance measures.

In order to overcome these limitations, in this contribution we propose a new family of measures which are designed to track the real-time mental processes unfolding during a rating evaluation. These measures are based on a mouse tracking paradigm and allow to record relevant cognitive information inferred from the motor control of the computer-mouse during online ratings. The new measures are assumed to be observable indicators of the dynamic process of rating which constitute the antecedents of the final rating outcome and they will allow a) to decompose the observed total rating time into a sequence of temporal subcomponents such as, for example, initiation time, pause time, verification time, and submovement time, characterizing some relevant temporal features of the rating process b) to represent the final response in terms of an activation value which measures the level of intensity/strength for that response. Finally, in our approach both the components are integrated into a common functional model which allows to express the combined temporal and intensity levels of rating. In order to show some important characteristics of our proposal, we applied it to some empirical rating situations concerning decision making and deception assessment scenarios.

Response Time Variability in an Inhibitory Control Task Reflects Statistical Learning and Adaptive Decision-Making

Ma, Ning, and Yu, Angela.

Response time (RT) is an oft-reported behavioral measure in psychological and neurocognitive experiments, but the high level of observed trial-to-trial variability in this measure has often limited its usefulness. Here, we combine computational modeling and psychophysics to examine the hypothesis that fluctuations in this noisy measure reflect dynamic computations in human statistical learning and corresponding cognitive adjustments. We present data from the stop-signal task, in which subjects respond to a go stimulus on each trial, unless instructed not to by a subsequent, infrequently presented stop signal. We model across-trial learning of stop signal frequency, P(stop), and stop-signal onset time, SSD (stop-signal delay), with a Bayesian hidden Markov model, and within-trial decision-making with an optimal stochastic control model. The combined model predicts that RT should increase with both expected P(stop) and SSD. The human behavioral data (n=20) bear out this prediction, showing P(stop) and SSD both to be significant, independent predictors of RT, with P(stop) being a more prominent predictor in 75% of the subjects, and SSD being more prominent in the remaining 25%. The results demonstrate that humans indeed readily internalize environmental statistics and adjust their cognitive/behavioral strategy accordingly, and that subtle patterns in RT variability can serve as a valuable tool for validating models of statistical learning and decision-making. More broadly, the modeling tools presented in this work can be generalized to a large body of behavioral paradigms, in order to extract insights about cognitive and neural processing from apparently quite noisy behavioral measures. We also discuss how this behaviorally validated model can then be used to conduct model-based analysis of neural data, in order to help identify specific brain areas for representing and encoding key computational quantities in learning and decision-making.

Sequential sampling models account for processing orders

Diederich, Adele

Payoffs may choice frequencies in perceptual decision tasks. Several studies affect investigating this effect have shown that sequential sampling models account for choice probability and choice response times when applying different payoffs. Typically payoffs are presented before the perceptual stimuli. Here, two more experimental setups are employed. In the second condition, payoffs are presented after the perceptual stimuli, and in a third condition, payoffs and perceptual stimuli are presented simultaneously. The predictions of four different sequential sampling models are shown for the manipulated processing orders: bound-change

model; drift-change model; mixture-of-processes model, and multi-stage processing model (aka multiattribute attention switching (MAAS) model). The qualitative and quantitative models' account for the data are discussed.

Signal detection and threshold modeling of confidence-rating ROCs: A critical test

Kellen, David, and Klauer, Karl Christoph.

An ongoing discussion in the recognition-memory literature concerns the question whether recognition judgments reflect a direct mapping of graded memory representations (a notion that is instantiated by signal detection theory) or whether they are mediated by a discrete-state representation with the possibility of complete information loss (a notion that is instantiated by threshold models). These two accounts are usually evaluated by comparing their (penalized) fits to Receiver Operating Characteristic (ROC) data, a procedure that is predicated on substantial auxiliary assumptions, which if violated can invalidate results. We show that the two accounts can be compared on the basis of critical tests that invoke only minimal assumptions. Using previously-published ROC data we show that confidence-rating judgments are consistent with a discrete-state account.

Sources of random variability in crossmodal reaction time

Colonius, Hans, and Diederich, Adele.

Trial-to-trial variability is an inherent feature of behavioral responses and the principal reason to conceive of reaction time (RT) as random variable. While RT variance (or related indices) are routinely reported as a descriptive measure, their theoretical status has not been studied intensively. Here, within the context of the temporal-window-of-integration concept, we investigate the sources of RT variability in the crossmodal condition and how crossmodal variability compares to unimodal variability. We show that crossmodal RT variance can be decomposed into several additive components by conditioning on the event of integration either occurring or not occurring in a given response trial. We find that the covariance between first and second stage processing times can be positive, negative, or zero depending on how the event of integration affects average processing times in both the first and second stage. We reveal a necessary condition for crossmodal variance to be strictly smaller than unimodal variance. Even without adopting a parametric model, like the ex-Gaussian, stringent tests of the time window hypothesis can be derived from these results, as soon as certain auxiliary assumptions are being made about how experimentally controlled variables affect the model parameters.

Speed-accuracy tradeoff in decision-making, and in personality.

Rae, Babette, Evans, Nathan, Bushmakin, Maxim, Rubin, Mark, and Brown, Scout.

Decision-making underpins much of daily life, from simple perceptual decisions about navigation through to life-changing decisions about love. At all scales, a fundamental task of the decision-maker is to balance competing needs for caution and urgency: fast decisions can be more efficient, but also more often wrong. We examine a link between this speed-accuracy tradeoff in two very different paradigms. One paradigm is the relatively standard approach, using perceptual decision-making with fast decisions (less than one second, roughly). The other paradigm invovles a personality trait known as "need for closure", which considers caution and urgency on a time scale of minutes to years.

Testing Random Utility Using Falmagne's Conditions Directly

McCausland, William James, Davis-Stober, Clintin, Marley, Anthony, Park, Sanghyuk, and Brown, Nicholas.

We evaluate the random utility hypothesis by testing a set of necessary and sufficient conditions on choice distributions. These conditions, discovered by Falmagne (1978), take the form of linear inequalities on various choice probabilities; all choice probabilities on doubleton and larger subsets of the master set (or universe) of choice objects appear in these inequalities. We designed and ran an experiment in which each of 81 participants chooses six times from each of the 26 doubleton and larger subsets of a master set of five choice objects. The objects are lotteries, and resemble those in an experiment described in Tversky (1969), whose design was intended to elicit intransitive revealed preferences. We analyze our data using Bayesian methods. We compute Bayes factors in favour of random utility, against an alternate model where choice probability distributions are unrestricted, and measure the sensitivity of these Bayes factors to the prior specification. For a large majority of participants in the experiment, choice data support the random utility hypoth- esis. There is moderate evidence against the hypothesis for two participants and strong evidence against it for one other participant. Evidence for and against random utility is fairly robust to the choice of prior.

The Advantage Linear Ballistic Accumulator: A New Model for Multi-Alternative Forced Choice Tasks

van Ravenzwaaij, Don, Brown, Scout, Marley, Anthony, and Heathcote, Andrew.

Over the last few decades, cognitive psychology has seen an advent of sequential accumulator models that aim to fit response time data from forced choice tasks. When the number of response options is higher than two, these models tend to posit one accumulator per response option: evidence accumulation is conceptualized as absolute evidence for one response option. Here, we propose a new model for sequential evidence accumulation in which evidence is collected relative to other response options: the advantage linear ballistic accumulator. In the first part of this paper, we present three kinds of model architectures that differ in terms of the conditions that have to be met for a response to be chosen. We demonstrate in model simulations that all of these architectures naturally produce Hick's Law (Hick, 1952). In the second part, we present fits of one model architecture (the Win-All model) to an empirical Hick's Law data set. In the third part of the paper, we discuss a recent claim by (Teodorescu & Usher, 2013), that in order to account for some empirical multi-alternative forced choice data, sequential accumulator models need mutual inhibition. We present fits of the Win-All model that does not include mutual inhibition to data by (Teodorescu & Usher, 2013).

The Dynamics of Single Item and Associative Recognition

Cox, Gregory E., Criss, Amy H., and Shiffrin, Richard M.

Associative recognition differs from the recognition of single items in that it requires relational information to distinguish between pairs of items that had been studied together versus those that had been studied separately. The process by which this relational information is accessed may be a form of recall in which one item is used as a cue to retrieve the second item, or the formation of a compound cue consisting of configural information that is independent of the information conveyed by each item alone. A compound cue mechanism predicts that the time at which relational information becomes available—and the speed with which it is accessed–is independent of both the strength of the individual items and of any studied associations. This is because cue formation occurs at retrieval and does not depend on what had been stored, in contrast with a recall process which predicts that relational information should be accessed earlier and/or more quickly as items and associations are strengthened. In a review of the speed-accuracy trade-off (SAT) literature and in new studies using response time methodologies, we find that the dynamics of association recognition are more consistent with compound cue formation than with recall. We present a formal model of associative

recognition via compound cue formation that is a direct extension of a model of the dynamics of single item recognition (Cox & Shiffrin, 2012). In addition to explaining qualitative features of the data, the model provides good quantitative fits to response time distributions and SAT functions in both single item and associative recognition.

The Fragile Nature of Context Effects in Multi-alternative Choice

Trueblood, Jennifer S., Brown, Scout, and Heathcote, Andrew.

Over the past few decades, researchers have shown that people's preferences are sensitive to context. That is, preferences for existing options can be altered by the introduction of new alternatives. Three different contexts effects – attraction, similarity, and compromise – have attracted a great deal of attention because they violate the properties of most utility models of choice. In an attempt to explain these three context effects, researchers have turned to dynamic, evidence accumulation models of decision-making. In the past, these models have been evaluated on their ability to simultaneously capture all three context effects with a single set of parameters. This naturally leads to the question of how "robust" the three context effects are within participants. However, most past experiments of context effects have been between subjects. In a new experiment, we examine the co-occurrence of the three effects within individuals. Our results reveal that the three effects are very fragile and only a small subset of people show all three simultaneously. We also show that a priori predictions from the Multi-attribute Linear Ballistic Accumulator model closely match our experimental results.

The Stepwise Analysis of Unsupervised Concept Learning Decisions

Doan, Charles A, and Vigo, Ronaldo.

Unsupervised category construction decisions can take a number of guises. One approach involves the free partitioning by humans of a set of objects into subcategories (Ahn & Medin, 1992; Handel & Imai, 1972; Imai & Garner, 1965; Medin, Wattenmaker, & Hampson, 1987; Milton & Wills, 2004; Regehr & Brooks, 1995). We show that, this approach, although useful in understanding category construction, is not sufficiently constrained to eliminate potential alternative interpretations in model and theory building. We take a more stepwise constrained approach where participants are asked to add to (construction task) or to remove from (deconstruction task) a single object, then two objects, then three, and so on, to categories defined over multiple dimensions that conform to particular predefined relationships between their dimensional values (i.e., category structures). A number of sorting results,

hitherto unexplained, can be teased apart with this approach (Regehr & Brooks, 1995). Furthermore, we show that tested construction and deconstruction decisions from our empirical investigations are consistent with the invariance-pattern detection mechanism described in generalized invariance structure theory (GIST; Vigo, 2013, 2014, 2015) and with representational information theory (RIT; Vigo, 2011, 2012, 2014, 2015). Lastly, we demonstrate how the one-dimensional sorts observed with traditional sorting paradigms (Ahn & Medin, 1992; Medin et al., 1987; Milton & Wills, 2004; Regehr & Brooks, 1995) may be explained with our stepwise analysis and GIST.

The deteriorating effect of mental imagery on item and source memory

Krefeld-Schwalb, Antonia, and Klauer, Karl Christoph.

The present project investigated the effects of mental imagery on item and source memory in two experiments. To manipulate the engagement in mental imagery, subjects had to solve a task, after encoding every stimulus, which was related to the visual characteristics of the stimuli. In one condition, solving the task required subjects to engage in mental imagery; in a control condition, the task could be solved without mental imagery based on visual perception. At test, subjects finally had to remember the stimuli, that is recognize the item and remember its condition (with or without imagery), the source of the item. We also manipulated whether memory for item and source was tested simultaneously or sequentially. The data were modeled with hierarchical Bayesian multinomial processing tree MPT models and hierarchical drift diffusion models. This procedure enabled the replication and cross validation of the estimated parameters and drawn interpretations across substantially different models. The parameters of the MPT model were estimated on the trial level to consider item, subject and condition effects, as well as specific influences of the stimuli's ease of imagery and typicality. Likewise, we estimated trial specific distributions of the driftrate. Mental imagery, in this paradigm, decreased the probabilities of item and source memory and the corresponding driftrates. This effect was weakened as the stimuli's ease of imagery increased. We interpret this finding with regard to the effects of cognitive effort during encoding, on memory accuracy.

The dynamic timecourse of similarity

Hendrickson, Andrew, Navarro, Daniel, and Donkin, Chris.

In the current work we use a computational model of reaction time to formalize and test predictions of if and how similarity changes over time. The similarity between items is most often conceptualized as either a sub-cognitive atomic process of sensory processing (ie Medin

& Schaffer, 1978) or a process that unfolds through randomly sampling features (ie Nosofsky & Palmeri, 1997). Both of these theories are consistent with reaction time models in which the evidence accumulation rate of similarity is constant across time. Alternative accounts of similarity (Goldstone & Medin, 1994) argue that the components of similarity become available to processing at different times and thus over time the evidence accumulation rate should change and even show sign reversals in certain conditions.

We compare these theoretical accounts in an experiment using a same-different task with stimuli from Goldstone & Medin (1994). Responses from earlier or later in the process of constructing the similarity between items were elicited by emphasizing either speed or accuracy in the instructions. A hierarchical diffusion model was fit to the data in each instruction condition and the posterior distribution across parameter values suggests that the rate of evidence accumulation was systematically different across instruction conditions. Furthermore, for the most difficult stimulus type we find a qualitative reversal in evidence direction. We will discuss this result and the implications of these findings for computational models of similarity.

The linear operator model: Learning in the Naming Game

Batchelder, William H., and Gosti, Giorgio.

The linear operator model (LOM) of Bush and Mosteller dates back to the early 1950s, and it was one of the earliest contributions to mathematical psychology. The LOM has a number of nice properties, e.g. it predicts asymptotic learning under constant reinforcement, it predicts probability matching under Bernoulli reinforcement schedules, and it satisfies a theoretically desirable combining of classes property. An important and neglected property of the model is that it is a bounded Martingale, and under conditions of uninstructed learning (making a response is its own reinforcement) one response, randomly, beats out all others in the limit. Many years ago the LOM ceased to be important for psychological learning theory; however, it is used today in areas like evolutionary game theory and the engineering sciences.

The naming game is played on a directed graph. The nodes in the digraph are players who are seeking a stable name for an object, and the dyads (arcs) consist of potential speaker/listener pairs. Initially each player has a prior probability distribution over the list of candidate names for an object. On every trial, a dyad is chosen from the digraph, and the speaker proposes a name for the object to the listener, and as a consequence both of their probability distributions change. There are a variety of conditions on the digraph, coupled with suitable reinforcing rules that lead to convergence in the limit to a single name for the object. The main result in this paper is that regardless of the size of the digraph, if it satisfies certain reasonable properties, convergence with probability one to a single name occurs with

the LOM under uninstructed learning regardless of the nature of the initial prior biases of the various players. For example, suppose the digraph consists of two huge, separate, connected components with but a single mutual dyad connecting the components. Further suppose the nodes in each component start, respectively, with different prior names for the object, each with probability one. Then the LOM with uninstructed learning would lead in the limit to all players converging on the same, single name for the object.

The role of relations and attributes in inductive inference

Xie, Wenting, and Austerweil, Joseph Larry.

Many problems faced by the mind can be cast as problems of inductive inference: generalizing a property from given stimuli known to have the property to a test stimulus. One proposed solution to inductive problems involves similarity; that is, generalize when the test stimulus is similar to the given stimuli. Although both attributes and relations shared by the given and test stimuli can influence similarity judgments, previous work suggests that relations play a much greater role in determining similarity judgments (Medin, Goldstone, & Gentner, 1990). One interpretation of this finding is that people have a prior bias towards using relations to determine similarity and perform inductive inference. Alternatively, Tenenbaum and Griffiths (2001) argued that relations tend to be more specific (fewer stimuli have any given relation); therefore, there is no bias towards relations, and the observed "bias" is merely a consequence of the size principle (more specific hypotheses receive more weight).

To test whether the size principle is sufficient to explain the bias towards using relations in similarity judgments and inductive inference, we defined a Bayesian generalization model in the domain of shapes. Using the model, we formulated three theories of relational bias: (1) strong relational bias, where the model only contains relations, (2) weak relational bias, where the model assigns higher prior probability to relations than attributes, and (3) no relational bias, where relations and attributes have equal prior probability.

We tested the three theories by comparing their generalization predictions to human behavior in an inductive inference task where we manipulated the amount of evidence given to the participant and whether the pieces of evidence were consistent with only attributes, only relations, or both attributes and relations. To evaluate the theories, we fit a parameter encoding the relative prior weight assigned to relational hypotheses relative to attributional hypotheses (the prior was otherwise uniform within each class of hypotheses). Our preliminary findings suggest that people have a strong, though not indefeasible, bias towards relational hypotheses; thus, the size principle is insufficient in itself to explain the previously found relational biases.

The triangle inequality constraint in similarity judgments

Yearsley, James, Barque-Duran, Albert, Scerrati, Eliza, Hampton, James, and Pothos, Emmanuel.

Since Tversky's (1977) seminal investigation, the triangle inequality, along with symmetry and minimality, has had a central role in investigations into the fundamental constraints on human similarity judgments. The meaning of minimality and symmetry are straightforward, but the significance of the triangle inequality is less clear. In part this is because, unlike minimality and symmetry, it is difficult to extract a quantitative constraint on similarity judgments from Tversky's qualitative discussion.

Expressed in terms of distances in psychological space, the triangle inequality reads Distance(A,B)+Distance(B,C)>Distance(A,C), where A, B, and C are any three stimuli. However it is not obvious how this is to be translated into a constraint on human similarity judgments.

We show how we can translate this constraint into one for similarities, using Shepard's (1987) generalisation law, and so derive a multiplicative triangle inequality in terms of similarities. Can humans violate this multiplicative triangle inequality? An empirical demonstration shows that they can. Finally, we discuss a recent similarity approach, based on quantum theory, which can accommodate violations of this inequality.

There is no fixed item capacity in working memory: Using a slots model to falsify a slots model

Donkin, Chris, and Taylor, Robert.

It has been proposed that the capacity of working memory is characterized by a fixed number of items. According to some, this limit is independent of the complexity of the items. Contrary to this view, performance in memory tasks tends to decrease as item complexity increases. Proponents of a fixed-item capacity claim that the drop in performance with item complexity is due to a 'comparison' process, such that the comparison between the contents of memory and test items is more error-prone when the items are complex. Here, we apply a hierarchical Bayesian model that estimates an item-based capacity measure as well as the accuracy of the comparison process. We show that both the accuracy of the comparison process, and the number of items in memory vary with the complexity of memoranda, and the way in which the items are presented.

Topology, order, and imprecise numerical representation

Zhang, Jun

Characteristic of comparative judgments in psychophysics or other cognitive/behavioral settings is the presence of "threshold." This ubiquitous phenomenon makes the construction of measurement scale challenging, because one needs to incorporate intransitive indifference relationship in numerical representation of stimulus intensity. Luce (1956) first proposed the concept "semi-order", which was later shown to manifest a threshold structure when represented on the real line (Scott-Suppes representation). Later, semi-order (and its fixed-threshold representation) is known to be a special case of the more general "interval order" (admits interval graph representation succinctly characterized by Fishburn; interval order), which is a special case of biorder (investigated Falmagne, Doignon, and many others). In this talk, I will report recent progress (with my students) regarding constructing an imprecise numerical representation based on order theory and topology (in particular, Alexandrov topology). Within intransitive indifference, we further differentiate a "nesting" relation, which is a partial order (irreflexive, asymmetric, transitive) itself, and an "overlapping" relation, which is a tolerance relation (reflexive and symmetric). It turns out that various degrees of pairwise topological separation (T0, T1, T2) characterize these binary relations.

Using Ranking Judgements in Comparing Models of Visual Working Memory

Taylor, Robert, LePelley, Mike, and Donkin, Chris.

A major debate in modeling Visual Working Memory (VWM) is whether item storage is best described by a discrete (e.g., slots) or continuous (e.g., resources) process. We first present data from a series of experiments which used multiple response data to test the predictions of the slots model, the results from which suggesting that item storage is better described by a resource process. We then addressed how a more complex slots model might better predict our empirical data. Accordingly, we derived a slots and resource model for the ranking task and conducted Bayesian model comparisons. Though the slots model could capture some features of the data, the additional complexity required in order to do so ultimately lead to poorer consistencies between model predictions and data when compared to the resource model.

Using alien coins to test whether simple inference is Bayesian

Cassey, Peter, Hawkins, Guy E., Donkin, Chris, and Brown, Scout.

Inference is a ubiquitous part of everyday life. Previous work has demonstrated that inference can be framed as statistically optimal Bayesian inference. We describe a quantitative test of this Bayesian analogy against human experimental data. We explored the conditions under which the Bayesian analogy holds in a simple inference task. Participants were presented with a scenario where only two types of coins existed, both with different head/tail probabilities. Before and after seeing a series of coin flip outcomes, participants needed to make an inference about which of the two coin types was being flipped. Overall participants behaved in a manner inconsistent with what would be expected if they were updating their beliefs via an approximation of Bayes rule. Elements of the inference task had to be reduced to a straight-forward level in order to induce participants to make inferences more consistent with optimal Bayesian inference. In light of the apparent suboptimal behavior we explored potential likelihood functions which participants would need to implementing if they were indeed updating their beliefs optimally.

Using experience sampling to understand how people isolate when personal events occurred

Sreekumar, Vishnu, Dennis, Simon, and Sederberg, Per.

To understand how people reconstruct the temporal source of real-world memories, we recruited twenty one participants who wore a smartphone in a pouch around their necks during an experience sampling phase of two weeks. A custom lifelogging application installed on the phone automatically captured images and other sensor data. On the Thursday of the third week, participants underwent a week discrimination test in which they were shown an image and were asked to identify which week it belonged to: week 1 or week 2. The serial position curve of the mean P(correct) shows an elevated performance across week 1 and at the end of week 2 but a significant decrement in performance at the beginning of week 2. We show that this apparently complex pattern can be explained by a simple distance-based model (cf. Friedman, 1993) that assumes that participants apply a criterion to a decaying memory strength function. We present a hierarchical Bayesian fit of the model to the data. To address an unresolved debate surrounding the nature of the retention curve in autobiographical memory, we employ a model selection measure to show that an exponential function provides a better description of the memory strength curve than a power function. Finally, we demonstrate that given their individual noise and decay rate parameters, most participants adopt an optimal criterion that maximizes performance across both weeks. We conclude that the

use of modern lifelogging technology combined with quantitative modeling provides a useful platform to revisit important questions about memory and more generally, about cognition.

Using the root mean square error of approximation as a goodness-of-fit index in diffusion model analysis

Schubert, Anna-Lena, Hagemann, Dirk, Bergmann, Katharina, and Voss, Andreas.

The statistical evaluation of model fit is one of the greatest challenges in the application of diffusion model analysis (Ratcliff, 1978). Relative GOF indices such as the AIC and BIC are often used for model comparison, but they provide no information about absolute model fit. Statistical and graphical tests can be used to identify individuals whose data cannot be accounted for by the diffusion model, but they become either overly sensitive when trial numbers are large or are subjective and time-consuming. We propose that the evaluation of model fit may be supplemented with the root mean square error of approximation (RMSEA; Steiger & Lind, 1980), which is one of the most popular and most frequently used GOF indices in structural equation modeling. It is not only largely invariant to trial numbers, but it also allows identifying cases with poor model fit, to calculate confidence intervals, and to conduct power analyses. In two simulation studies, we evaluated whether the RMSEA correctly rejects bad-fitting models in diffusion model analysis irrespective of trial numbers. Moreover, we compared whether RMSEA values for good-fitting models in the diffusion model framework were comparable to values typically observed for good-fitting models in structural equation modeling. For this purpose, we simulated data sets a) from diffusion models with different numbers of free parameters, and b) from distributions that closely resemble empirical RT distributions as well as from distributions that are unrelated to empirical RT distributions. We varied the number of trials, the degree of noise, and the number of estimated parameters. Our results indicate that the RMSEA correctly distinguishes between good- and bad-fitting models unless trial numbers are very low. Moreover, RMSEA values were in a value range expected from structural equation modeling. Finally, we computed cut-off values as heuristics for model acceptance or rejection.

Utility of machine learning approaches for developing accurate and affordable behavioral markers of drug addiction

Ahn, Woo-Young, Ramesh, Divya, Moeller, F. Gerald, and Vassileva, Jasmin.

Recent advancements in decision science and quantitative methods provide a framework for understanding normative and abnormal behavior in a coherent way. Drug addiction has been

extensively studied with the decision-making framework to understand its symptoms and underlying neurobiology. Abundant evidence indicates that drug addiction is characterized by impulsivity and decision-making deficits, which are some of the most promising potential markers of drug addiction that may innovate its prevention and treatment.

Here we present two machine-learning studies, which demonstrate that behavioral measures of impulsivity and decision-making can accurately classify current and past drug users. In Study 1, we recruited current stimulant (cocaine) users and healthy controls (HCs) in USA who completed self-reports of trait impulsivity and several laboratory tasks assessing response inhibition and decision-making. A machine learning model was fitted on the training set using 5-fold cross validation and we tested its out-of-sample classification accuracy in the test set. The area under the curve (AUC) of the ROC curve was 0.90 in the test set. In Study 2, we tested HCs and individuals with past mono-dependence on heroin or amphetamine, currently in protracted abstinence. The study was done in Bulgaria where poly-substance dependence is still uncommon. Machine learning analyses revealed that the AUC of the ROC curve in the test set was 0.85 and 0.75 for the classification of past heroin and amphetamine dependence, respectively. Heroin and amphetamine dependence were predicted by distinct multivariate patterns of impulsivity/decision-making deficits. The predictive profiles of stimulant users (current cocaine users in Study 1 and past amphetamine users in Study 2) were highly similar.

Our results demonstrate the promise of machine-learning approaches to extract features predictive of group membership and highlight how decision science and advanced statistical methods can inform clinical science. The results suggest that behavioral measures of impulsivity and decision-making can be objective markers of drug addiction. The results also suggest that different mechanisms may underlie stimulant and opiate addiction, challenging the unitary account of drug addiction. This line of work may shed light on the development of affordable and easy-to-administer standardized tests that can be used to assess individuals' risk to different classes of drugs in clinical settings.

Posters

A Cultural Consensus Theory Analysis of Crowdsourced Transcription Data

Deshpande, Prutha Shantanu, Jameson, Kimberly A., Tauber, Sean, Chang, Stephanie M., Gago, Sergio, and Narens, Louis.

Cultural Consensus Theory (CCT) is a formal process model used to derive information from a shared knowledge domain when the "correct answers" are uncertain. We applied CCT to the analysis of internet-based crowdsourced responses, collected with the aim of transcribing a large handwritten cross-cultural survey dataset (MacLaury, 1997). Prior to this study, it was unknown whether CCT could serve as an appropriate model for assessing the accuracy of survey information collected via crowdsourced procedures, or if it could be useful for converting handwritten documents into data-addressable files. This study provides a preliminary investigation of such uses of CCT. We compare a standard Bayesian CCT model (Oravecz et al., 2014) with an alternative implementation of CCT that permits the use of multiple-choice/free-response data. The alternative model makes the non-standard assumption that response bias is based on perceptual confusability of stimuli and response options for each question, and therefore varies across items but not across individuals. Accurate transcription results were obtained with both implementations for dichotomous-type questions, supporting the continued use of the alternative implementation. Further analyses of multiple-choice/free-response data found all of the alternative model's criteria for fit to be satisfied, indicating the appropriateness of CCT for such data. Interestingly, two variations found accuracy of consensus solutions greatly improved by the inclusion of data from expert respondents, and by considering data of only a subset of participants who responded to the task with high confidence. Implications of these analyses and uses of CCT in large-scale crowdsourced data collection platforms are discussed.

A Dual-process Model of Framing Effects in Risky Choice

Guo, Lisa, Trueblood, Jennifer S., and Diederich, Adele.

This work investigates the influence of time pressure on framing effects in risky decision-making. These effects occur when participants exhibit risk adverse behavior in choices framed as gains and risk seeking behavior in choices framed as losses. Researchers have suggested that framing effects are the result of two different systems of reasoning – one that is fast and emotional (the intuitive system) and another that is low and rational (the deliberative system) (De Martino et al., 2006; Kahneman & Frederick, 2002). Specifically, researchers have argued that use of the intuitive system results in increased framing effects. Because this system is characterized as being fast, we expect more pronounced framing effects under time

pressure. In our study, we introduce both a time pressure condition (requiring participants to respond quickly and make a choice in 1000 ms or less), and an accuracy condition (instructing participants to maximize the amount of money earned with no time limit). We use a dynamic dual-process model to explain our results. The model we develop is a sequential sampling model in which the drift rates and boundaries vary in accordance with the thinking modes, frames, and time pressure. Drift rates in the model are defined according to subjective values as calculated by prospect theory, and we assume that the intuitive system precedes the deliberative system so that there is a switch in drift rates during the course of a trial. Our model is able to capture the framing effects found in both our studies and previous findings.

A Model of Stage Change Explains the Average Rate of Stage of Development and its Relationship to the Predicted Average Stage ("Smarts")

Commons, Michael Lamport, Miller, Leonard Sidney, and Giri, Sagun.

A number of different previous methods for measuring "smarts" have led to the Model of Hierarchical Complexity (MHC), a context free neo-Piagetian mathematical model of behavioral complexity. It provides a way to classify tasks as to their hierarchical complexity. Using the Model of Hierarchical Complexity, this study examines how differences in rate of stage change results in a difference in the highest average stage (smarts") attained by 70 year old adults. The average stage of development ("smarts") was shown to be predicted by the log of age with an r = .79. It uses data from Colby, Kohlberg, Gibbs, Lieberman (1983) to test the model. It also predicts that on the average there is one stage of development during adulthood.

A Rational Model for Individual Differences in Preference Choice

Ahmad, Sheeraz, and Yu, Angela

Human preference choice suffers curious contextual effects: the relative preference between two multi-attribute options (e.g. cars with differing safety and economy ratings) can dramatically shift, depending on the presence/absence of additional options. This phenomenon defies any simple utility-based account of choice, and has been taken to imply irrationalities/suboptimalities in human decision-making, or reflect idiosyncrasies in neural processing. Recently, we used a Bayesian model to show that these contextual effects are normative consequences of observers' using options to learn about the "market". However, it had an unsavory implication that all decision-makers asymptotically converge to the same beliefs/behavior. Here, we propose a new model that uses both market and personal utilities to make choices. This model still captures the contextual effects, while also allowing asymptotic differences

in individual preferences and providing a general framework for explaining how consumption informs one's beliefs and preferences.

A cognitive latent variable model approach to the transfer-of-training effect

Kupitz, Colin Nicholas, Buschkuehl, Martin, Jaeggi, Susanne, Jonides, John, Shah, Priti, and Vandekerckhove, Joachim.

We use a cognitive modeling approach to reanalyze the data from a transfer-of-training study. By fitting a diffusion model to the participant behavior over sessions, we can draw conclusions as to the underlying causes of any behavioral changes – such as increasing familiarity with the stimuli, speed of information processing, paradigm adaptation, or changes in cognitive strategies. The diffusion model we use revealed simultaneous behavioral adaptations: a speed-accuracy tradeoff, an increase in non-decisional response speed, and an increase in speed of information processing. These three adaptations transferred to a similar non-trained task. Further, we explore a cognitive latent variable model that introduces a set of latent learning parameters. We use this model to investigate how changes in performance on the trained task – interpreted as learning – correspond to measured improvement on the transfer tasks.

An analysis of sequential sampling models of reaction time in the case of transient detection and identification

Meyer, Jordan, and Zhang, Jun.

Transient signals (stimuli with relatively short duration from onset to offset) are ecologically common, and the brain has clearly evolved mechanisms to respond to them. However, most modern sequential sampling models of reaction time (RT) take as their paradigmatic case that of sustained signals (stimuli whose duration generally exceeds the time elapsed until initiation of response). Psychologically, for stimuli that have disappeared before a response, standard drift rate parameters interpreted as "stimulus strength" must be reinterpreted using various additional assumptions. For example, Smith et al. (2004), in a study of transient masked signals, hypothesized that decision-related information accumulation is based on stable representations of stimuli in visual short term memory. In the case of Bayesian RT models, the classic optimality results of SPRT-like approaches are no longer guaranteed in the domain of transient signals. This is especially salient for tasks involving stimulus identification in addition to detection. In the present work, we review the approaches that have been taken in the modeling of RT with respect to transient signals, within both the psychological and statistical sequential analysis literature. We next investigate the statistical properties of a

number of novel candidate models for both transient detection and identification, and discuss their psychological validity.

Attention versus Expertise in memory

Bennett, Stephen, and Steyvers, Mark.

When an individual navigates their environment, they are tasked with attending to and remembering important details and objects. Some (experts) perform better than others. In a novel memory task, we collect data from individuals who are tasked with remembering several objects from complex scenes. We implement multiple graphical models to infer the underlying effects that dominate memory and determine the relative effects of attention and expertise. Results are discussed in terms of Wisdom of the Crowds applications for memory.

Consistency of Muscle Test Results

Wilson, Jennifer Renee, Baribault, Beth, Young, Emily Anne, Guild, Hannah Elizabeth, and Vandekerckhove, Joachim.

Muscle testing, also known as "applied kinesiology," is a widely used diagnostic technique in alternative medicine. Proponents of muscle testing believe that one can determine the suitability of a natural supplement for an individual using a brief "muscle resistance test" that involves a trained muscle tester applying pressure on a patient's arm while they hold a natural remedy close to their chest. Resistance to the pressure implies compatibility with the supplement whereas low resistance implies incompatibility. We will present results from an experimental study on the inter-rater reliability of muscle test results.

The experiment involved a group of experienced muscle testers, who were provided with five unmarked bottles containing different natural supplements. The testers were then asked to rank the suitability of the supplements for each of 20 participants. Our goal was to evaluate whether muscle testers are able to detect a genuine signal through the testing procedure. To test this, we evaluated the correspondence between rank orders that different muscle testers provide for the same participant.

We developed a novel Bayesian inference procedure to evaluate the psychophysical properties of muscle testing. We computed Kendall's tau for all comparisons between the muscle testers' rank-orders within each tested individual and compare the null hypothesis (of no agreement) to a set of alternatives under which different muscle testers give rank orders with different degrees of correspondence.

Depression and Intertemporal Choice of Pain: Maximum Likelihood Estimation vs. Hierarchical Bayesian Analysis

Sakamoto, Jiro, Somatori, Keita, Okubo, Matia, and Kunisato, Yoshihiko.

Depression facilitates the avoidance of immediate physical pain (Vlaeyen and Linton, 2000; Asmundson et al., 2004) depending on the overestimation of pain intensity (Breslau et al., 2003). Such decision making exacerbates future pain. Therefore, depression becomes a risk factor for chronic pain onset (Carroll et al., 2004). However, it remains unclear how people with depression estimate future pain and make decisions based on that estimation. This study aimed to examine the relation between depression and intertemporal choice of pain. Sixty-eight undergraduates (28 males, 40 females, mean age = 21.1) took part in the experiment. We administered an intertemporal choice task with imaginary pain (Story et al., 2013) and the Patient Health Questionnaire-9 (Kroenke et al., 2001; Muramatsu et al., 2007). All participants provided written informed consent prior to the experiment. To investigate each participant's decision-making process, we adopted the seven mathematical models proposed by Story et al. (2013). The parameters of delayed pain including waiting cost (i.e., dread) and discount rate were included in the models. The probability of choice was modeled by softmax function, which included the inverse temperature. These parameters were estimated using maximum likelihood estimation (MLE). We found the negative time preference (i.e., "get it out of the way") and confirmed that dread and delay discounting are stable components of future pain. Our results showed that depression affects inverse temperature (estimated by summary statistic approach [Daw, 2009]). However, MLE has some problems such as parameter distribution biases and potential inaccuracy of the estimated value, so we re-analyzed the data using hierarchical Bayesian modeling. Bayesian inference showed better performance of estimation and predictions than MLE (e.g., no local optimum solution and no divergence of likelihood in Bayesian analysis). We found that depression affects inverse temperatureãĂĂestimated by hierarchical Bayesian modeling.

Discrete-State and Continuous-Strength Models of Recognition Memory: Lure Detection in the Context of Strong Versus Weak Targets

Malejka, Simone, Heck, Daniel W., and Erdfelder, Edgar.

In a recent recognition-memory study using a four-alternative ranking task, Kellen and Klauer (2014) found that the conditional probability of targets being assigned rank 2 given that they were not assigned rank 1 is higher for strong than for weak targets. The finding was interpreted as supporting the signal-detection model but contradicting the two-high-threshold model of recognition memory. According to the latter, failure to assign rank 1 to targets can

be seen as evidence for target non-detection. Hence, the target's memory strength should not affect the assignment of targets to ranks 2, 3, and 4. However, this prediction only holds if lures are detected with the same probability in the context of strong versus weak targets. Given that target and lure detection are typically correlated, this need not necessarily be true. To test whether lure detection improves in the context of well-learned targets, performances in a two-alternative forced-choice task conditional on target ranks exceeding 1 in a subsequent ranking task were contrasted using strong versus weak targets. Implications for the debate whether performance in recognition-memory tasks should be measured assuming continuous memory strength or discrete memory states are discussed.

Generalized Invariance Structure Theory Accounts for the 3[4] Family Ordering for both Integral and Separable Dimensions

Barcus, Karina-Mikayla, Vigo, Ronaldo, and Zhao, Li.

Nosofsky and Palmeri (1996) studied categorization performance on the family of category structures corresponding to four objects defined over three binary integral dimensions. In their experiment, they observed an ordering that is significantly different to the well-known Shepard, Hovland, and Jenkins (1961) learning difficulty ordering when the stimulus dimensions are separable. In what follows, we show that Generalized Invariance Structure Theory and its core model (the GISTM without free parameters) can account for both the canonical separable dimensions ordering and the integral dimensions ordering observed by Nosofsky and Palmeri. The basic idea is to use the more general version of the GISTM (Vigo, 2013, 2014, 2015) which uses the Minkowski distance as opposed to the Euclidean distance measure to determine the degree of categorical invariance. By setting the Minkowski parameter to 1 (Manhattan Metric) for integral dimensions and to 2 (Euclidean Metric) for separable dimensions, both orderings are naturally predicted within the same framework. The rationale is that, at the category (global) level of analysis, the distance computations are reversed from those at the object exemplar (local) level of analysis: that is, the ambiguity involved in determining invariance patterns with respect to integral dimensions activates a resources sharing mechanism that approximates the Euclidean distances between ideotypes in psychological space with the less accurate, but computationally simpler, Manhattan metric.

Identifying Functional Networks in Brain Imaging Data

Gaut, Garren

Years of behavioral research suggest that human cognitive abilities consist of several major components that are manifested in the brain mostly through interactions in the frontal and

parietal cortices. Interactions in parietal and frontal cortex are able to predict individual differences in intelligence and reasoning tasks, and functional networks between the frontal lobe and other brain regions are significantly correlated with intelligence. Typical functional connectivity studies in fMRI proceed in a confirmatory fashion–that is, researchers choose a theoretically motivated seed brain region and use correlations in functional activation between the seed region and other brain areas to predict task performance. The presented work details exploratory analysis of fMRI imaging data that models task scores as a function of pairwise correlations in activity between brain regions from a pre-specified set of brain regions of interest. Importantly, this allows for the inference of functional networks that can be used to classify task and predict task performance. We compare a regularized logistic regression model on task classification for 250 subjects in 9 tasks and find that both models can predict task with high accuracy. We use the model to visualize functional networks predictive of each task. We regress task performance on correlations between brain regions of interest and visualize functional networks that predict performance.

Information-Processing Architectures in Reading: An Investigative Application of the Systems Factorial Technology

Zimmer, Kyle Michael, and Fific, Mario.

For years, psycholinguists have been debating over the mental architecture associated with various processes that take place in the context of processing human language. Today, some of the most prominent psycholinguistic reading models disagree over whether the reading of adjacent words occurs in a parallel or serial fashion. The Systems Factorial Technology (SFT) is a rigorous and highly diagnostic methodology that has been used to draw similar distinctions in visual search, categorization, face perception, and other areas commonly studied by cognitive psychologists. The methodology allows us to determine within subjects: a) the mental architecture of two processes (serial or parallel), b) a stopping rule (self-terminating or exhaustive), and c) process dependency. In the current study we applied the SFT methodology to test the serial and parallel hypotheses in the processing of adjacent words in a self-paced reading task. Participants were asked to read simple sentences and answer a brief comprehension question after each. The sentences were presented fully masked at first. Then by clicking a mouse button participants were able to unmask two words at a time, with the previously viewed words again being masked. To apply SFT a researcher must selectively manipulate the difficulty and accordingly the speed of each process in a set of processes of interest. In our case the two processes were the reading of two adjacent words, and we experimentally manipulated the visual saliency of each word in a pair by making the text light grey or black. SFT was conducted along this dimension of visual saliency as

well as along two dimension implicit to the task: word-length and word-frequency. In all three cases we found evidence that individual differences may exist with regard to the mental architectures and stopping rules employed by readers.

Latent structure of attention: A cognitive latent variable model approach.

Baribault, Beth, and Vandekerckhove, Joachim.

Many models of cognition are designed to analyze homogeneous data sets, composed of data from a single paradigm. However, this is often not realistic: Real data sets are high-dimensional and include a heterogeneous assortment of data types. To infer the latent cognitive processes that have produced such complex data, we have designed a new type of model called a cognitive latent variable model (CLVM). CLVMs allow for simultaneous assessment of individual differences and latent structure by combining a cognitive process model of the data with a psychometric model of underlying structure.

The first component of a CLVM is a latent variable model. For this particular model, we developed a Bayesian implementation of exploratory factor analysis. This allows the model to uncover structure in the data by identifying latent ability variables and quantifying the relationship between each latent variable and scores on the observed task variables.

The second component of a CLVM is a cognitive process model, in this case a diffusion model for two-choice reaction times. Reaction time is a complex and noisy measure, as it not only reflects speed of processing, but also reflects response bias, caution, and time for stimulus encoding and motor response execution. With the diffusion model, we are able to decompose choice reaction time into cognitive parameters that reflect each of these aspects. Including this cognitive model allows the factor analysis to operate only on the speed of processing parameter, which is a clearer measure of cognitive ability than raw choice reaction time. The simultaneous implementation of a cognitive (diffusion) model and the latent variable (factor analysis) model leads to the CLVM framework.

We demonstrate the capabilities of this model using attention as a case example. Data was collected through a small battery that included two established attention tasks (Continuous Performance Test and Attention Network Test) and two self-report measures of attention-related behavior. This produced 12 reaction time measures and two covariate measures per participant. The CLVM was successfully used to reduce the dimensionality of this dataset and thereby uncover a smaller set of latent variables that reflect underlying attention abilities.

Although we describe an application to attention here, CLVMs could be used to analyze latent cognitive abilities underlying heterogeneous data from any number of cognitive domains.

Modeling Confidence Judgments in Perceptual Discrimination

Voskuilen, Chelsea, and Ratcliff, Roger.

We present an application of the RTCON2 model of decision-making (Ratcliff & Starns, 2013) to data from two perceptual tasks (brightness discrimination and motion discrimination). This model was designed to account for response times and response proportions from confidence judgment tasks and has previously only been fit to data from recognition memory tasks. Here we test the model's ability to fit data from two perceptual tasks: a dot-motion paradigm and brightness-discrimination paradigm. In both tasks, subjects exhibited response patterns and response time effects similar to those previously observed in recognition memory experiments with confidence judgments and the RTCON2 model was able to produce all of these effects.

Multiple Strategies in Conjunction and Disjunction Judgments: Most People are Normative Part of the Time

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

Do people use a single strategy or sample from multiple strategies when estimating the conjunction and disjunction of two independent events? Here we address this tension directly by comparing individual level Bayesian simulations of multi and single strategy models using data from a frequency estimation experiment. Participants were shown two statements describing attributes and asked to estimate how many people had either one attribute, conjunction, or disjunction of attributes. In our Bayesian simulations we compare models in which participants either adopt a single strategy or sample from a set of strategies when forming estimates of both conjunctions and disjunctions. We compared every permutation of models in which a participant is responding based on a single component, a weighted average of the two events, probability theory, or combination of strategies. Our findings show that people sample from multiple strategies and are sampling from the normative strategy some of the time.

Primary-stage responses to balance scale tasks simulated in a hierarchical stacked neural network model

Leite, Sofia, Lamport-Commons, Michael, and Rodrigues, Pedro.

We are initializing the development of a Hierarchical Stacked Neural Network model, a connectionist model composed of hierarchical stacks that generate increasingly complex outputs.

This is a new approach for simulating cognitive development, which follows from the theoretical underpinnings of Commons's Model of Hierarchical Complexity. Each stack represents a stage of development; hence, each higher-order stack increases by 1 the order of complexity of lower order outputs and similarly increases by 1 the order of complexity of the tasks that can be solved.

In the present work, we simulated data from the Balance Scale test. By defining primary-stage tasks, we aimed to verify whether primary-stage actions can be generated by compositions of sigmoid functions and optimized through the gradient descent technique (or a variant). To this end, we tested two different computational designs of primary-stage balance scale tasks. Task 1 concerned the typical XOR problem; task 2 required the network to learn two linear boundaries for discriminating three classes.

Results suggest that a 1 hidden unit connectionist model is able to reproduce primary-stage actions. A more straightforward way to achieve this learning capability is to choose Task 2 definition, once the network behavior is more robust, independently of the network characteristics.

Besides the successful results in this particular situation, we further argue that the Hierarchical Stacked Neural Network model encompasses a suitable architecture for capturing the progression of human performance independently of the task, as does the Model of Hierarchical Complexity.

Probabilistic Inference as Transportation of Measures Between Sample Spaces

Shi, Zifu, and Zhang, Jun.

Sample space in probability theory refers to the set of all possible outcomes of an experiment or possible values of a random variable. Probability measures are defined with respect to an associated sample space. When there are more than one random variables (and hence more than one sample spaces) involved, the feasibility of construction of a sample space unconditionally conjoining all these variables has been the dividing line between classical and quantum probability theories and their applications to cognitive modeling. Here we propose that uncertainty reasoning in humans involves both the construction of positive measures over individual sample spaces and transportation of these measures across different sample spaces. Hence, joint probability measures are not meaningful without specifying a mechanism of probability normalization (e.g., Luce's Choice Axiom) and a mechanism of probability transport ("transporter", or conditional probability). Analytically, the Kullback-Leibler deviation between two joint probability measures can be decomposed into two additive terms related to, respectively, normalization and marginalization (Zhang, SMP'2013). We examine the feasibility of this "sample-space" theory of human uncertainty reasoning to provide

a unified language for various paradigms of reasoning using two random variables, namely, base-rate neglect in Bayesian reasoning, order-effect in sequential judgment, probabilistic causal reasoning, etc.

Release from output interference in cued recall: Cue-target dissociations

Wilson, Jack H., and Criss, Amy H.

Output interference (OI), studied first in terms of recall processes and more recently in terms of recognition processes, is the observation that memory performance declines with additional testing. Release from OI (ROI) is the observation that this interference can be ameliorated if the category of the tested material changes partway through a test phase. A typical ROI experiment simultaneously varies the category of the memory cue and the tested material. In cued recall the cues and the to-be-retrieved targets can be manipulated independently. To investigate the relative contributions of similarity among cues and targets, we implemented a ROI experiment in cued recall. The outcome suggests that OI is driven by similarity among the memory cues rather than similarity among the to-be-retrieved targets. Implications for models of memory will be discussed.

Single-trial EEG measures of visual attention predict psychological parameters during perceptual decision making

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

Joint reaction time (RT) and accuracy data from two-alternative forced choice tasks are well fit by diffusion models, a class of sequential sampling decision-making models. Fitting behavior to diffusion models has the added benefit of producing parameter estimates that have psychological interpretations such as evidence accumulation rate, within trial accumulation variance, and non-decision time. During a visual decision making task, subjects chose the correct mean orientation of a circular field of small oriented bars that were embedded in visual noise. We concurrently recorded steady-state visual evoked potentials (SSVEPs), induced EEG responses to flickering visual stimuli that have been shown to track visual attention. Using phase information from the SSVEPs as inputs in a hierarchical Bayesian fit of the diffusion model, we show that differences in evidence accumulation rate, within trial accumulation variance, and non-decision time across trials and subjects can be explained by single-trial measures of subjects' visual attention. Out-of-sample accuracy and RT data are shown to be well predicted by the hierarchical model with single-trial SSVEP inputs.

What is a true measure for meta-cognition?: A Bayesian cognitive modeling approach.

Somatori, Keita, Sakamoto, Jiro, Shimotomai, Atsushi, and Kunisato, Yoshihiko.

Meta-cognition is defined as thinking about one's cognition. Various procedures are used to measure meta-cognition because the concept is very broad. Koriat and Goldsmith (1996) provided an experimental method for measuring meta-cognition. In this method, participants are asked to follow three steps: (1) answering a general knowledge question, (2) estimating their confidence in answering the question, and (3) deciding whether they would add the question to their total score. In the task, step (1) is positioned to reveal cognitive processes, and steps (2) and (3) are positioned to reveal meta-cognitive processes. A meta-cognitive index is calculated based on the behavioral data. For example, Koren et al. (2004) proposed meta-cognitive index. Although previous study provided meta-cognitive index based on behavioral data, this index does not clarify what kind of cognitive processes are used. The Bayesian cognitive modeling approach allows researchers to apply their model to the data and to estimate latent cognitive variables. This study aimed to examine Bayesian cognitive modeling used to measure meta-cognition. Seventy-eight undergraduates and graduate students (35 male, 43 female; mean age = 21.13) took part in this study. All participants provided written informed consent prior to the experiment. Participants were asked to respond to a meta-cognitive task and meta-cognitive questionnaire-30 (MCQ-30, Yamada & Tsuzi, 2007). In Bayesian cognitive modeling, we integrated theoretical framework proposed in previous research and then proposed our Bayesian meta-cognition model. We estimated meta-cognition and cognitive ability using our Bayesian meta-cognition model and hierarchical Bayesian analysis. Cognitive characteristics were estimated using the Item Response Theory model. Although our results showed high positive correlation between the meta-cognitive index and cognitive characteristics, there was no significant correlation between the estimate of meta-cognition and cognitive ability. Additionally, we found that negative correlation between the estimate meta-cognition for the meta-cognitive task (Koriat & Goldsmith, 1996) and MCQ-30 score. In conclusion, measurement of meta-cognition based on Bayesian inference is useful. We suggest that meta-cognition should be estimated using our Bayesian meta-cognition model.

Why people frequently commit the base-rate fallacy

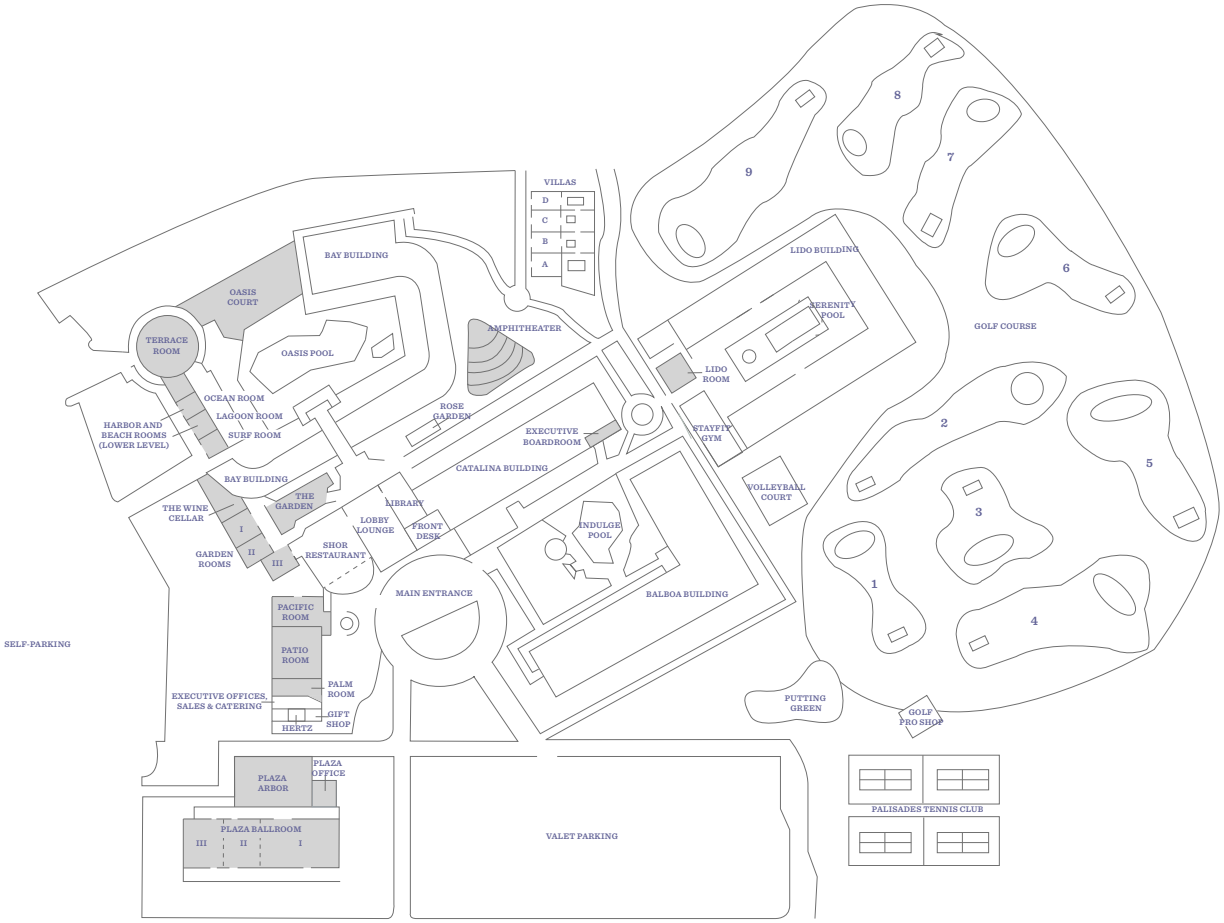
Tanaka, Toshio, Kunisato, Yoshihiko, Okada, Kensuke, and Okubo, Matia.

In probability estimation task, our intuitive reasoning or judgement under uncertainty often

profoundly differs from normative probability. For example, many studies have been shown that base-rate is often neglected in probability judgement tasks. Several hypotheses explain why people frequently commit this base-rate fallacy. One of these is called "equiprobability hypothesis". This hypothesis argues that base-rate fallacy is observed because people fallaciously consider P(H) to be equivalent to P(D). If this hypothesis is correct, the percentage of correct answer would increase when one knows a priori, from context cue, that P(H) is different from P(D). Hattori & Nishida (2009) tested this idea in their experiment, and the results partially supported it.

The current study extends this line of research by manipulating the ease of recall with alternative cues. Moreover, following the suggestion of DeNeys, Schaeken & d'Ydewalle (2005), working memory capacities of the participants are also measured by Japanese Operation Span Test and are built into the analysis. The results of the experiments are analyzed by using log linear analysis and Bayesian cognitive modeling.

Hotel Map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HARBOR AND BEACH ROOMS (LOWER LEVEL)
ROSE GARDEN
EXECUTIVE BOARDROOM
STAYFIT GYM
CATALINA BUILDING
VOLLEYBALL COURT
BAY BUILDING
THE GARDEN
LIBRARY
THE WINE CELLAR
LOBBY LOUNGE
FRONT DESK
INDULGE POOL
GARDEN ROOMS
SHOR RESTAURANT
MAIN ENTRANCE
BALBOA BUILDING
PACIFIC ROOM
PATIO ROOM
SELF-PARKING
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