32^{nd} Annual Meeting of the Society for Mathematical Psychology: Abstracts

29 July to 1 August, 1999
University of California, Santa Cruz

- **Friday, 30 July** [1].

8:00AM: CHOICE, MEASUREMENT, AND STATISTICS

- A. A. J. Marley, *McGill University*, and R. Duncan Luce, *University of California, Irvine*, **A simple axiomatization of binary rank-dependent expected utility of gains (losses)**.

  For binary gambles composed only of gains (losses) relative to a status quo, the rank-dependent expected-utility model with a representation that is dense in intervals is shown to be equivalent to ten elementary properties plus event commutativity and a gamble partition assumption. The proof reduces to a (difficult) functional equation that has been solved by Aczel, Maksa, and Pales (submitted).

- R. Duncan Luce and Robert Sneddon, *University of California, Irvine*, **Reduction invariance and Prelec's weighting function**.

  Prelec (1998, Econometric) axiomatized a form for the weighting function in utility models, namely, $W(p) = \exp[-\gamma(-lnp)^{\eta}]$. Gonzalez and Wu (1999, Cognitive Psychology) showed it to provide a good fit to their data. In this paper, a simpler axiomatization is offered that is based on two major assumptions. One is separability in the sense that $U(x, p; 0) = U(x)W(p)$. The other is the behavioral property, called reduction invariance, that if $((x, p; 0), q; 0)$ $(x, r; 0)$, then for $N = 2, 3((x, p^N; 0), q^N; 0)$ $(x, r^N; 0)$. This assumption is then generalized to a broad class of families of weighting functions of which, however, Prelec's is the only one that includes as a special case the "rational" property that $r = pq$. Of the several functions that have been proposed, Sneddon and Luce (submitted) show that the Prelec function is best for 83% of 144 subjects.

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- William H. Batchelder and Bethany Knapp, *University of California, Irvine*, **Predicting response time phenomena in binary choice from Luce's choice theory**.

  The Bradley-Terry-Luce paired -comparison system predicts choice probabilities but not response times. We reparameterize the system in terms of an equivalent system which postulates parameters a_i for each choice object i, with $0 < a_i < 1$. Then choice of object i from the pair $\{i, j\}$ is given by

  $$p_{i,j} = \frac{a_i(1 - a_j)}{a_i(1 - a_j) + a_j(1 - a_i)}$$

  This expression is shown to be generated recursively by an infinite branch, multinomial processing tree (MPT) model, or equivalently a three-state Markov chain of the sort proposed by Bower in a 1950s article titled "choice point behavior."

  The MPT representation generates a probability distribution over the number of links in a branch leading to overt choice in terms of the choice object parameters. We regard the number of links as proportional to mean response time. We add bivariate distributions, $f(a_i, a_j)$, on the choice parameters for a pair i, j to reflect parameter heterogeneity over trials or participants. By designating one of the two choice objects as the "correct" response, we are able to account for most of the known relationships between choice probability and response times on error and success trials. The moral is not that we have launched a new contender for the "correct" theory of response time, but instead that there are lots of ways to fit data, and more specifically to account for choice-response time phenmomena.

- Matthew Jones and Jun Zhang, *University of Michigan*, **Learning to cooperate in a prisoner's dilemma game under Markov framework**

  In the two-person prisoner's dilemma (PD) game, the defect-defect (D/D) strategy pair is a Nash equilibrium, i.e., neither player has incentive to unilaterally deviate. That the D/D pair is

remarkably stable (at least normatively) can be appreciated from the fact that it is the combination of the dominant strategy for BOTH players. It has been argued (by backward induction) that if the PD game is played for a finite number of times, the "always defect" pair of strategies is still the strong Nash equilibrium, and therefore no learning towards mutual cooperation is possible – contrary to what has been observed behaviorally in the experimental gaming literature. To resolve this conflict between individual and collective (Pareto) rationality, we assume that agents are operating in a Markov environment of repeated PD games, with infinite length but geometric discounting for reward, or equivalently and more realistically, with stochastic length but no discounting for reward. The state space is defined as the set of possible outcomes over the last m games (yielding 4^m possible states), where m is a parameter corresponding to memory span. Dynamic programing methods then give each agent optimal policies for maximizing total reward. For the case of one-back memory ($m = 1$), the equations are tractable; the best responses to all $2^4 = 16$ deterministic strategies (including "tit-for-tat") have been determined. Interestingly, while tit-for-tat can induce the opponent to cooperate under all circumstances (i.e., the best response to it is "C regardless"), this strategy itself is not among the best response set to any of the 16 strategies. This raises the question of validity of the stationarity assumption of a Markov framework. To fully explore the consequences of the stationary model, we are characterizing the topology of the Nash equilibria manifold in the entire mixed strategy space, and considering longer memory spans ($m > 1$) in modeling agents' behavior. Computer simulations are performed where agents follow the standard reinforcement algorithms such as temporal difference and Q-learning. The goals are to reconcile individual and Pareto rationality and to compare the complex strategies that arise with human behavior.

- George Karabatsos, *Louisiana State University Medical Center*, **Representational measurement theory and item-characteristic curves: Implications for selecting item-response models**

  Much work in item-response theory involves considering the Rasch model, two-parameter logistic model (2PL), and three-parameter logistic model (3PL) to analyze a data set, and the best-fitting model is decided as the "appropriate model." This paper argues that the analyst also needs to consider the scientific principles these models are based on. If the intention is to measure persons, then mathematical structure of the item-response model needs to support interval scaling. This study theoretically and empirically evaluates the three models capacity to support interval scaling, and describes what interval-scaling requires of item-characteristic curves. A simulation study reveals that almost 100% of the time, the parameters of 2PL and 3PL violate interval scaling. On the other hand, the theoretical probabilities of Rasch models always support a stable, interval scale structure. Therefore, if the intention is to construct stable interval measurement, data should approximate uniform item-characteristic curves. The argument that 2PL and 3PL are advantageous because they are "less restrictive" alternatives to Rasch models (Hambleton & Swaminathan 1985; van der Linden & Hambleton, 1997) does not recognize the connections between linear measurement requirements and uniform ICCs. Because of their added parameters, 2PL and 3PL may be more accommodating to data. But if data is being approximated to expected values contradictory to linear and stable measurement, fit becomes an irrelevant issue.

- Michael H. Birnbaum, *California State University, Fullerton*, **WWW experiments test properties of decision making**

  Many Decision Making theories imply or assume transitivity, consequence monotonicity, and coalescing. These theories imply satisfaction of stochastic dominance. Rank-dependent expected utility models (RDEU), including RSDU, and CPT models imply (in addition) restricted co-monotonic branch independence. Such models imply tail independence and two cumulative independence properties. Six Internet experiments, with more than 700 judges in each, asked people to choose between gambles. People knew they might be selected to play one of their chosen gambles and win as much as $110. Violations of stochastic dominance, lower cumulative independence, upper cumulative independence, tail independence, Allais independence, and probability ratio independence were observed. As in previous research, judges showed risk aversion for medium and high probabilities and risk neutrality or risk seeking for low probability events. The data are not consistent with EU or RDU models,

but they remain compatible with the configural weight, TAX model.

8:00AM: INFORMATION PROCESSING I

- Hans Colonius, *Oldenburg University*, **Visual-auditory interaction in space and in time: An integrated modeling approach for divided and focused attention tasks**.

  In a visual-auditory focused attention task the subject gives a speeded (saccadic or directed manual) response to a stimulus from one modality while a stimulus from the other modality, presented in certain spatio-temporal proximity, can be ignored. Typically, response time to the target stimulus is affected by (a) the spatio-temporal configuration of both stimuli and (b) the presence or absence of the non-target stimulus. We present a (rather) general two-stage serial model with dependent sub-stages, report several empirical tests, and discuss the model's extension to divided attention tasks, where the subject is free to respond to either stimulus modality.

- Bruce Bridgeman, *University of California, Santa Cruz*, **Sensory memory arises from lateral inhibition**.

  A model of lateral inhibitory interactions in sensory systems, based on the Ratliff-Hartline equations and modified for mammals, stores information after sensory signals have ceased. Each neuron in a network of identical neurons inhibits its neighbors after a time delay, by an amount determined by an inhibitory coefficient that declines with distance. Information reverberates in the interacting neurons, creating patterns characteristic of the original stimulation. Since the system of equations is linear (except for thresholds), information remains stored indefinitely. Addition of Gaussian noise at each iteration of inhibition, simulating neural noise, degrades the information, measured by correlating two runs of the model under identical conditions but with statistically independent noise in each run. Using physiologically derived values for the duration of an iteration of lateral inhibition, correlations of two runs remain high for 90-240 ms after stimulus offset with realistic amounts of noise, reflecting preservation of stimulus-specific information. Sensory memory falls out as a natural concomitant of the lateral inhibition that is known to be present in sensory systems, with no additional machinery and no free parameters.

- Jennifer McLean, *University of Washington*, **Processing capacity of visual perception and memory encoding**.

  The visual system is often conceptualized as a limited-capacity information-processing system. This notion of limited capacity explains how performance for any one item declines with increases in the number of other items processed simultaneously: A limited amount of processing capacity must be divided between items. This effect has been attributed to capacity limits in perception, memory encoding, both, or neither. In this study, capacity limits in perception and memory encoding were measured and compared using closely matched search and memory tasks. The search and memory tasks differed only in that the target was presented before the stimuli set for search versus after the stimuli set for memory. Stimuli were small ellipses varying in contrast, orientation, and size. Set sizes were 1 and 4. Increasing set size always decreased performance, and more so for memory than for search. These effects were modeled using a Signal Detection Theory approach with a parameter for the degree of limited capacity. This parameter was employed as a theoretical measure of capacity limits that varies from zero for unlimited capacity to one for fixed capacity. By this measure, the results suggest perceptual capacity is only slightly limited while memory-encoding capacity is sharply limited. The limit of the combined processes of perception and memory encoding was consistent with fixed capacity. Compared to previous studies, this analysis provides a more quantitative measure of the degree of limited capacity.

- David Huber, Keith Lyle, and Richard Shiffrin, *Indiana University*, **Short-term priming: Data and a model for bias and interference**.

  Primes precede a briefly flashed and post-masked word, followed by two choices. Niether, one, or both choices are related to the primes (when both are related, priming is unbiased). The relation of a prime to a choice is in various conditions associative, identity, or orthographic. Unbiased orthographic and unbiased identity priming produce a large performance decrease. Passive processing of primes produces a large bias to choose the related choice when only one is related, but active processing eliminates or even reverses the bias. Our model assumes perceived features arise from the flash, noise, and the primes, the

source being unidentifiable. A Bayesian decision model uses estimates of the source probabilities to determine the evidence favoring either choice. The model accounts for the interference effects, the presence or absence of bias, and the interactions of these with similarity of alternatives and primes. We discuss the relation to previous short-term priming results and to attentional blink, repetition blindness, and negative priming.

- Javier R. Movellan, *University of California, San Diego*, and James L. McClelland, *Carnegie Mellon University*, **Factorability of information sources: Analysis and implications for models of perception**.

  Many experiments and demonstrations document the fact that the perception of a wide range of stimuli is affected by contextual information. Guided by a model that he called the logogen, John Morton predicted that in experiments that require identifying one of two alternatives the ratio of the choice probabilities of these alternatives should factorize into components independently controlled by stimulus and context. These components are interpreted as the relative support of the stimulus and context for the two alternatives under consideration. Massaro and colleagues have shown that this form of factorability of information sources provides good approximations to empirical response probabilities obtained in a remarkable range of domains such as word and letter perception, object identification, depth perception, memory retrieval and recognition of emotions.

  In this paper we analyze the conditions under which factorability reflects optimal perceptual inference and present a machine perception experiment with audio visual speech signals to support the analysis. We explore a class of neural network models defined via stochastic differential equations (SDE) to show that in such models factorability is not incompatible with feed-back and lateral connections but is an indication of an architectural constraint that we named "channel separability."

- Ehtibar N. Dzhafarov, *Purdue University*, **A complete characterization of unconditionally selective influence in processing architectures**.

  A vector of random variables (e.g., hypothetical RT components) $\{X_1, \ldots, X_n\}$ is unconditionally selectively influenced by a partition $\{G_1, \ldots, G_n\}$ of a set of factors G that influence $\{X_1, \ldots, X_n\}$ if, for $i = 1, \ldots, n$: (a) X_i is a smooth function of G_i and a random vector $\{R_1, \ldots, R_n\}$ whose distribution does not depend on G; and (b) any factor in G_i effectively influence the marginal distribution of X_i. This paper provides a complete characterization of this notion: the existence and form of the functions relating X_i to G_i and $\{R_1, \ldots, R_n\}$ are related to properties of the distribution function for $\{X_1, \ldots, X_n\}$. Together with the notion of conditionally selective influence characterized in Dzhafarov (1999), this work establishes the precise meaning(s) in which one can say that random variables while being stochastically interdependent are selectively influenced by distinct factors.

10:30AM: POSTERS[2]

- Robin. D. Thomas, *Miami University of Ohio*, **Classification training influences elementary perception of multidimensional objects**.

  In typical accounts of visual object recognition, the perception of attributes such as size, shape, color, etc., is assumed to occur prior to the classification of the object as a kind. Recently, researchers have begun to explore the effects of higher level cognitive processes on early perception. For example, it is known that when size and orientation of an object are perceived, the perceptual noise associated with one dimension is usually uncorrelated with that of the other. If, in the environment, within categories of objects, the two attributes were made to be physically correlated, the learning of the categories may cause the noise in the perception of a single object to become correlated. The present study explores the possibility that the classification goals of the perceiver influences early perceptual processing. Stimuli varying in size and orientation were classified by participants into one of two categories for many sessions. Observers also performed pre- and post-category visual identifications using a small set of stimuli formed from the orthogonal combination of both dimensions. Multidimensional signal detection analyses of the identification data were used to estimate the parameters of the perceptual noise both before and after category train-

[2]Posters will be available for viewing from 10:30 am until 4:30pm.

ing. For two of three observers, the correlation of the noise between attributes of size and orientation observed in the identification task changed from pre- to post-classification training in a way that reflected the learning of optimal decision processes. The third observer showed little effect.

- Christopher S. Campbell, Michael M. Cohen, Tony Rodriguez, and Dominic W. Massaro, *University of California, Santa Cruz*, **Model selection and Occam's Razor: A two-edged sword**.

  We extended the Myung and Pitt (1997) comparison of Bayesian Model Selection (BMS) and root mean square deviation (RMSD) methods of model selection. Their analysis failed to take into account (a) the overall goodness of fit as opposed to simply which model gave the better description of the results, (b) whether a model gave a statistically better fit for a group of participants than another model, and (c) generating data sets from different models produce very different data configurations and therefore are not directly comparable. Our re-evaluation of BMS and RMSD methods in symmetrical expanded factorial designs refuted the conclusions of Myung and Pitt (1997) by showing (a) RMSD recovers the original models about as well as BMS, (b) RMSD and BMS both show that WTAV fits FLMP data about as well as FLMP fits WTAV data, (c) BMS results in a bias for less complex models in the presence of noise while RMSD does not. We concluded that RMSD provides nearly as good measure of fit as BMS without requiring unsubstantiated assumptions in model testing or fairly expensive computational resources.

- Xiangen Hu, *The University of Memphis*, **Analyzing general processing tree models using GPT.EXE**.

  This paper introduces the recent implementation of GPT.EXE, a windows based software for analyzing General Processing Tree (GPT) models. GPT.EXE provide an ultimate tool for statistical inferences for the GPT framework. Using GPT.EXE, standard statistical analysis of parameter estimation, hypothesis testing, and goodness of fit can be conducted in Windows platform. Furthermore, GPT.EXE provides user-friendly features that allow researchers to conduct Monte Carlo simulations and power calculations. GPT.EXE also provide canonical ways to analysis contingency tables within the framework of GPT models.

- George Karabatsos, *Louisiana State University Medical Center*, and James R. Ullrich, *The University of Montana*, **Proximity between the additive, distributive, and dual-distributive rules of polynomial conjoint measurement: The case of $3 \times 3 \times 2$.**

  A Monte Carlo procedure evaluated the closeness between the additive, distributive, and dual-distributive composition rules of polynomial conjoint measurement, in the $3 \times 3 \times 2$ positive case. The results reveal five conclusions. First, there are far more distributive and dual-distributive tables than additive tables, as the number of distributive slightly exceeds dual-distributive. Second, distributive tables are more likely to satisfy joint independence than dual-distributive tables. Third, additivity implies distributivity and dual-distributivity. Fourth, with the exception of additive tables, distributive and dual-distributive tables are mutually exclusive. Fifth, Kendall's t correlation distributions reveal that additive, distributive, and dual-distributive tables are extremely similar. In fact, approximately 95% of all distributive and dual-distributive tables only require five or less sign alterations for the conversion to additivity. The fifth result has the strong implication that statistical goodness-of-fit methods, often used for numerical conjoint scaling procedures, are not able to effectively distinguish among the three composition rules with fallible data. This may be the case even with infallible data.

- Stephen Lloyd, *Rush Presbyterian-St. Lukes Medical Center*, and George Karabatsos, *Louisiana State University Medical Center*, **Correcting contaminated person measures by means of a three-factor conjoint measurement procedure**.

  An unresolved issue in personality assessment is the potential correlation of latent trait measures with traits of social desirability, acquiescence, or dishonesty (Nunnally, 1978). Previous attempted solutions to this problem have been proposed with techniques of true-score theory, which unfortunately produces nonlinear test- and sample-dependent measurements. To avoid these shortcomings, this study proposes a probabilistic three-factor additive conjoint measurement model. For dichotomous responses, the model specifies that the probability of person n endorsing item i is governed by the function

$$\ln\left[\frac{P\{X_{ni}=1\}}{P\{X_{ni}=0\}}\right] = B_n - D_i = (T_n + Q_n) - D_i$$

where $P\{X_{ni}=1\}$ is the probability of an item endorsement, $P\{X_{ni}=0\}$ is the probability of non-endorsement, B is the contaminated latent trait measure, composed of the pure latent trait measure T with the addition of contamination factor Q, and D is the item "difficulty" or non-endorsability. Derivation of the model is described. The model is then demonstrated in application to both simulated data and to a real data example. Potential applications to other experimental situations are discussed.

- Seongeun Kim, *University of Southern California*, **Robust moment structured modeling**.

  Outliers and non-normal data are quite common in educational and psychometric studies. A small proportion of outliers and slight change from normality can totally distort the analysis based on classical procedures in mean and covariance structured model. The most popular methods such as Maximum Likelihood method and WLS estimation methods including ADF and normal theory GLS are greatly affected by slight departure from normality and possess extremely low resistance against outlier-contamination.

  In the area of mean and covariance structured model, there were a lot of studies that investigated the problem of non-normality and outliers, and the non-robustness property of classical methods. Findings from previous studies reported in general all the estimators were greatly sensitive to the departure from normality and the upper tail of the distribution of the chi-square test statistic was too heavy. Thus, Type 1 error of the test statistics of model fit is inflated, the true structure being distorted. Therefore, robust methods are necessary for mean and covariance structured modeling.

  In our study we examine the problems of usual mean and covariance structured modeling with non-normal data and suggest the application of robust measures of location and scale to mean and covariance structured modeling. Simulation studies support the superiority of our proposed method.

- Gilly Naheer-Leshed, Ido Erev, *Technion*, Roger Remington, *NASA Ames Research Center*, Galia Shabtai, and Daniel Gopher, *Technion*, **A descriptive detection of change model for air traffic control tasks**.

  The current research tries to develop a descriptive model of decision making in Air traffic control (ATC) tasks. In a common ATC task the decision maker has to decide whether a course change is necessary due to an air conflict with other aircraft. This task can be abstracted as a binary Detection of Change (DC) task. Namely, the decision maker chooses among two alternatives, "no change" and "change," based on a noisy signal that accumulates over time.

  The first part of the paper reviews the behavioral regularities observed in previous studies of DC, and presents a model that captures these regularities and outperforms alternative models. The second part evaluates the generalizability of the model in experimental simulations of ATC tasks. In each trial of each task the participant saw an aircraft, represented by a dot, moving on the computer screen and had to detect when it changes its course. The results (of 8 experimental conditions) are consistent with the findings of previous studies of abstract DC tasks and can be captured by the model with high human power.

- Robert Homer and Bogdan Sasaran, *Beth Israel Medical Center*, **Information in the brain's neural networks: From psychical energy to infons, and beyond**.

  Applying the laws of physics to understand how information is stored in the brain and brought into consciousness is an old problem. By Freudian definition, the transformation of free psychical energy to bound psychical energy is a cathexis in which unconscious material may be made preconscious and thus available to consciousness. More recently, conscious awareness has been taken to be associated with the brain's "working memory" (Beardsley, 1997).

  Whatever the model, there is not a universally accepted methodology for describing the physics of information storage and transfer in the brain's neural networks. While it can be established that the brain abides by the second law of thermodynamics in terms of information theory, there is no well established understanding of what the nature of information in the brain is. A quanta of information called an "infon" has been proposed for such a purpose (Stonier,1997). The infon is defined as a massless particle, lacking energy, which propagates at a velocity up to, but

less than, the speed of light. In this paper we explore this concept, considering a similar particle that essentially travels at the speed of light, but with nearly zero frequency. It is hypothesized that this latter particle is more appropriate to a network of neurons where the information is maintained locally.

- Alan B. Cobo-Lewis, *University of Maine*, **Parameterization-invariant adaptive methods for psychophysics**.

  I have previously described an information-theoretic method for estimating multiple parameters of a psychometric function (SMP, 1996, Chapel Hill). The strategy was to choose stimulus parameters at each trial to maximize the Shannon mutual information between the stimulus parameters and the subject's response. For normally distributed parameters, this amounts to minimizing the expected volume of the variance-covariance matrix of the parameter estimates. This strategy is scale-invariant; that is, it is invariant with respect to linear transformations of the parameters. However, this strategy is not invariant with respect to nonlinear reparameterizations.

  Herein I discuss a differential geometric approach to the problem that draws from the work of Amari and others: one induces a metric on the manifold of probability distributions corresponding to the family of psychometric functions under consideration. The metric is parameterization-invariant. Relationships to issues in model selection (e.g., Jeffreys' priors) will be discussed.

- Shu-Chen Li, Ulman Lindenberger, *Max Planck Institute for Human Development*, and Peter A. Frensch, *Humboldt-University*, **Unifying cognitive aging: From neurotransmission to representation to cognition**.

  Cognitive aging research lacks overarching cross-level theoretical frameworks. Data and explanations of age-related cognitive deficits have been mostly confined within either the behavioral, information-processing, or biological level. To facilitate the integration of cognitive aging research, we tested an integrative theory linking cognitive aging deficits observed at the behavioral level with deficiency in neurotransmission causing less distinctive cortical representations in a series of neural network simulations. Specifically, age-related attenuation of dopaminergic function was simulated by lowering the mean gain of the processing units activation function, which subsequently reduces a units responsivity and raises spatial and temporal intranetwork activation variability. Benchmark phenomena such as age differences in learning rate, asymptotic performance, interference susceptibility, complexity cost, intra- and interindividual variability, and ability dedifferentiation can all be accounted for by gain reduction. These simulation results explicate dopamines role in regulating the fidelity of neural information processing and the subsequent effects leading to various cognitive deficits occurring during normal aging.

10:50AM: APPLICATIONS AND DEVELOPMENTS IN SIGNAL DETECTION

- Albert J. Ahumada, Jr., *NASA Ames Research Center*, **A flexible, nonparametric definition of threshold**.

  Standard methods for reporting thresholds from psychometric functions involve fitting a parametric function to the data and reporting one parameter of the function. For example, the function may be a cumulative normal with a ceiling representing a fixed proportion of guessing errors. The reported threshold parameter is then only indirectly related to observer performance. The observer may not be able to achieve the performance levels associated with the parametric function having the reported threshold levels and different "error rates." A local, nonparametric definition of threshold is proposed which is effectively independent of the fitting function and is directly related to performance. The local threshold is well defined where the psychometric function has a positive slope. A global threshold is defined to be the smallest of the local thresholds. An arbitrary scale factor can be set to make the global threshold equal to the standard threshold when the cumulative Gaussian alone is the fitting function.

- Jun Zhang and Shane T. Mueller, *The University of Michigan*, **Non-parametric estimate of sensitivity and response bias in signal detection framework**.

  Sensitivity and bias in 2×2 detection or discrimination experiments can be estimated directly (non-parametrically) from the observed hit rate (H) and false alarm rate (F). These measures, originally proposed by Pollack and Norman (1964) for sensitivity and Hodos (1970) for bias, became popularized after Grier (1971)

provided explicit computing formulae. However, Macmillan and Creelman (1996) challenged the rationale behind these ad hoc formulae and argued that, instead of being non-parametric and hence distribution free, these formulae actually conform to a particular model of decision-making, one based on the logistic distribution. Alternatively, Smith (1995) provided formulae to calculate sensitivity based on a different rationale: sensitivity is approximated as the average of the maximum and minimum areas of *all* admissible ROC curves passing through the data point (H, F) in the ROC space. Here we correct an error in Smith (1995) regarding the maximum area of data-constrained ROC curves. We also propose some new formulae as candidates for estimating response bias. These measures, including the previously published ones, will be compared against each other, and against the sensitivity and bias derived from the normal-normal ROC curves.

- J. D. Balakrishnan and Justin A. MacDonald, *Purdue University*, **Effects of bias on the psychometric function: A model-free perspective**.

  Using a new set of methods and analyses that do not require any model-related assumptions, we examined the effects of decision making biases on the shape of the psychometric function for comparative judgments of size. Results of the first experiment show that the dependence of this function on the presentation order (which stimulus is taken as the standard) is due to a bias (not necessarily intentional) in the decision rule. The effects of this bias can be removed in an assumption-free manner, producing the "true" psychometric function. In the second experiment, base rates are shown to have effects on both the decision rule and the encoding distributions, indicating that these two stages are not independent. Based on these findings and previous results, we argue that classical approaches to describing and quantifying the effects of bias, including the Thurstonian and signal detection theory measures, are wholly inadequate methods of analyzing decision making processes in perceptual classification, and should be replaced by the new methods described in this paper.

- Richard G. Swensson, *University of Pittsburgh*, **Fitting new ROC formulation based on probability summation**.

  An ROC formulation from probability summation is proposed for measuring performance with highly uncertain signals, like the detection of abnormalities found on medical images. The detection or rating decision is determined by a latent variable assumed to characterize the specific "possibility" (lesion type and location) deemed "maximally likely" to be the actual signal. For cases with signals (images containing lesions), this maximum variable is assumed to be either the signal's value (s) or that of the most suspicious normal finding (x)—whichever is larger—whose cumulative probability distribution at detection criterion Z is $P\{\max[s, x] < Z\} = F(Z)G(Z)$, where $F(Z) = P\{s < Z\}$ and $G(Z) = P\{x < Z\}$. The false-positive rate for non-signal cases (normal images) is presumably then $FP(Z) = P\{x > Z\} = 1 - G(Z)$, while the true-positive rate is $TP(Z) = P\{\max[s, x] > Z\} = 1 - F(Z)G(Z)$. Unlike the usual ROC formulation $[FP(Z) = 1 - G(Z), TP(Z) = 1 - H(Z)]$, this guarantees a "well-behaved" ROC curve that always equals or exceeds chance-level decisions [cannot yield $TP < FP$ or an upward "hook" in TP at high FP], whatever the assumed distribution functions $G(Z)$ and $F(Z)$. A maximum-likelihood PC application (Windows 95 or NT) now fits the constrained formulation to rating ROC data, using normal distributions with two free parameters (like usual fits of ROC curves). Those estimated parameters can then be used to predict the signal's probability of being both detected (above Z) and also correctly identified or located (by first choice) at any value for $FP(Z)$.

10:50AM: APPLICATIONS AND DEVELOPMENTS IN NEUROCOMPUTATION

- Hervé Abdi, *The University of Texas at Dallas* and Dominique Valentin, *Université de Bourgogne à Dijon*, **Projecting blondes and brunettes in PCA face space: Why is it easier to find the pose of brunettes?**

  Previous work (i.e., Valentin and Abdi, 1996) has shown that an image based PCA model (or equivalently a linear autoassociator) dissociates spontaneously between pose information and identity information. Specifically, eigenvectors with large eigenvalues serve as pose detectors, whereas eigenvectors with small eigenvalues serve as identity detectors.

  In this talk, we report a series of simulations and experiments showing that pose detectors do

not work equally well for all faces. In a first simulation, examination of the faces shows that the pose detectors perform very well for faces of brunettes but less so for faces of blondes. This leads to the obvious but rather counterintuitive prediction that the ability of human participants to process face orientation should be dependent upon hair color. Specifically, it should be easier to evaluate the orientation of faces of brunettes than of faces of blondes. Surprisingly, a first experiment, confirms that prediction. Human participants performed better when detecting changes in poses for brunettes than for blondes. A possible explanation of the brunette superiority effect is that both the PCA model and human participants are using low level information (such as texture) to detect orientation. Therefore, eliminating texture information by keeping only the edges of the image should also eliminate the brunette superiority effect. This is tested by a second simulation and experiment using filtered faces. As predicted, the brunette superiority effect disappears for both human participants and the model. However, human participants performed than chance. We conclude that texture favors brunettes, but that pose detection can be performed with edges only no matter what hair you have or not (to say it baldly!).

- Elliott M Waldron and F. Gregory Ashby, *University of California, Santa Barbara*, **Dopamine mediated deficits in category learning: A computational model**.

  Category learning deficits have been observed in a wide variety of neuropsychological disorders. These deficits appear to be of two distinct types: (a) deficits affecting the accrual of associations between exemplars and categories (as in Knowlton, Mangels, & Squire, 1996, Science), and (b) deficits affecting the ability to apply logical strategies (as in the Wisconsin Card Sorting Test). These results challenge current neuropsychological theories, as well as current theories of category learning. A recent neurocomputational model called COVIS (Ashby, Alfonso-Reese, Turken, & Waldron, 1998) is tested against category learning data from a variety of neuropsychological conditions, including depression, frontal lobe pathology, and Parkinson's disease. COVIS assumes there are multiple category learning systems, and assigns key roles to the caudate nucleus, prefontal cortex, anterior cingulate, as well as the neurotransmitter dopamine. A neural network implementation of COVIS successfully accounted for deficits from each of these populations only using the parameters of the model associated with endogenous levels of dopamine.

- Dan Rizzuto and Michael Kahana, *Brandeis University*, **An autoassociative neural network model of paired associate learning**.

  We analyze both linear and non-linear variants of an autoassociative neural network model of paired associate learning. In these models, learning is based on a probabilistic encoding algorithm, and we allow the correlation between forward and backward associative strength to vary. Applying this model to data from successive cued-recall tests, we find that in order to mimic experimental results, the models require a near perfect correlation between parameters controlling forward and backward associative strength at the level of individual pairs. We also discuss the roles of parameter variability and output encoding in determining inter-task contingencies. The resulting analysis provides insight into the information processing involved in associative memory and supports the view that associations between symbolic elements are better conceptualized as a blending of two ideas into a single unit than as a link connecting two preexisting nodes in memory.

- Nilendu G. Jani, *Iconoci, Inc.*, and Daniel S. Levine, *University of Texas at Arlington*, **A neural network theory of analogy-making and conceptual relationships**.

  A neural network model that can simulate the learning of some simple proportional analogies is presented. These analogies include, for example, a) red-square : red-circle :: yellow-square: ?, b) apple : red :: banana : ?, c) circle shape : "circle" :: square shape : "square." Underlying the development of this network is a theory for how the brain learns the nature of association between pairs of concepts. The types of context-dependent interlevel connections in the network suggest a semilocal type of learning that in some manner involves association among more than two nodes or neurons at once. Such connections have been called synaptic triads, and related to potential cell responses in the prefrontal cortex. Some additional types of connections are suggested by the problem of modeling analogies. These types of connections have not yet been verified by brain imaging, but the work herein suggests that they may occur and, possibly, be

made and broken quickly in the course of working memory encoding. In these connections, one can learn transitions such as "keep red the same"; "change red to yellow"; "turn off red"; "turn on yellow," and so forth. Also, the network includes a kind of weight transport so that, for example, red to red can be transported to a different instance of color such as yellow to yellow. The network developed here is based on common connectionist building blocks such as associative learning, competition, and adaptive resonance along with additional principles suggested by analogy data.

- Jerome Busemeyer, *Indiana University*, and Mark McDaniel, *University of New Mexico*, **The conceptual basis of function learning and extrapolation: A hybrid connectionistic rule based model**.

  One important way that concepts are used is to learn functional relationships between continuous variables and make predictions about one variable on the basis of another. There are innumerable examples that we encounter everyday such as predicting job performance based on intelligence, anticipating mood level based on stress intensity, forecasting interest rates based on unemployment rate, and so on. The purpose of this article is to provide a foundation for a more formal, systematic, and integrative approach to function learning that parallels the existing progress in category learning. First we review some basic findings concerning function learning that must be addressed by any candidate theory. Next we review several potential models of function learning and describe how each model addresses these basis issues. Third we present new rigorous tests of the competing models.

1:30PM: INVERSE PROBLEMS IN PERCEPTION AND COGNITION (*Session organized by Zygmunt Pizlo, Purdue University*)

- Zygmunt Pizlo, Moses W. Chan, and Adam K. Stevenson, *Purdue University*, **A theory of binocular shape perception based on regularization**.

  Binocular space and shape perception is an ill-conditioned inverse problem. If the 3-D scene is reconstructed exclusively from the sensory information (retinal images, oculomotor depth cues), the result is extremely unstable in the presence of visual or oculomotor noise. To overcome this instability our theory uses a simplicity principle. Specifically, according to our theory the perceptual process begins with a monocular reconstruction of shape through the minimization of the complexity of the object, as measured by the departure of contours from planarity, departure from symmetry and variance of angles. The second stage, involving binocular disparity, leads to the correction of the global aspects of the shape. Simulation experiments showed that reconstructions produced by an algorithm based on this theory are at least one order of magnitude more accurate and stable than those produced by prior algorithms. Psychophysical experiments illustrate the psychological plausibility of the new theory.

- Bruce Bennett and Rachel Cohen, *University of California, Irvine*, **Directed convergence in stable percept acquisition**.

  We view a perceptual capacity as a non-deductive inference, represented as a function from a set of premises to a set of conclusions. We define stable percepts to be convergent sequences of instantaneous percepts. Assuming the sets of premises and conclusions are metric spaces, we introduce a strategy for acquiring stable percepts, called "Directed convergence." We consider the special case of probabilistic inferences, where the premise and conclusion sets are spaces of probability measures, and in this context we study "Bayesian probabilistic/recursive inference." Here the premises are probability measures and the prior as well as the posterior are updated nontrivially at each iteration, Thus, this type of Bayesian inference is distinct from classical Bayesian statistical inference where the prior remains fixed, and the posterior evolves by conditioning on successively more punctual premises. We indicate how directed convergence strategy can be implemented in the context of the Bayesian probabilistic/recursive inference. We discuss how the L-infinity metric can be used to give numerical control of convergence in this case.

- Michael S. Landy, *New York University*, and Pascal Mamassian, *University of Glasgow*, **A Bayesian analysis of biases in the perception of shaded line drawings**.

  It is well known that the human visual system is able to arrive at a single, well-defined, 3-dimensional percept in response to stimuli in which the 3-D solution is underconstrained. We

model this behavior through the use of a-priori constraints. A well-known example is the crater illusion: observers are biased to perceive the source of illumination as coming from above. We describe two studies using ambiguous stimuli. (1) Simple line drawings consisting of a few curved contours may be seen as elliptic (egg-shaped) or hyperbolic (saddle-shaped), depending on the orientation and aspect ratio of the figure. (2) A series of embossed ridges in a surface is cued both by shading and by contours painted on the surface (orthogonal to the ridges). Priors for shape-from-contour (discovered in the first study) and shape-from-shading ("light comes from above") cooperate or conflict depending on stimulus details. We develop Bayesian models that predict observer judgments, e.g. Prob("Say it's saddle-shaped" — Stimulus), as identical to posterior probabilities, Prob("It is a saddle" — Stimulus), a non-committing loss function. This conditional probability is computed using Bayes Rule and the geometry inherent in the stimulus situation, allowing us to estimate the parameters of priors that model the observer's biases.

- Benjamin T. Backus, *Stanford University*, and Martin S. Banks, *University of California at Berkeley*, **Estimator reliability theory predicts the perceived slant of cue-conflict stereo surfaces**.

  Theories of percept construction must explain how the visual system combines information from redundant sources. Recent experiments from several labs show that in many cases, the percept for cue-conflict stimuli is based on averaging, as in weak fusion models (Clark & Yuille, 1990; Landy et al., 1995). Such behavior probably reflects the normal operation of mechanisms that are robust to errors in the measurement of environmental signals: internal conflicts must be resolved routinely during natural viewing. We examined a particularly well-controlled visual scene—a random-dot plane that is slanted in depth—and the methods by which its slant could be known to the visual system. In this case, the reliable methods are stereoscopic, and the sources of useful information are horizontal disparity, vertical disparity, and eye position. Each of these sources can be parameterized by a scalar signal. The signals can then be combined to form a minimal set of slant estimators. The variance of each estimator depends jointly on the fixed noise in the measurement of the signals it uses, and the actual values of those signals (i.e., the scene). The hypothetical estimators were put into conflict by laboratory manipulation of the signals. Perceived slant can be predicted as a weighted average of estimator outputs, where weights are proportional to *reliabilities* (defined to be the reciprocal variances of the estimators for the current scene). Perceptual bias (e.g. a Bayesian prior) can be treated simply as an estimator with nonzero reliability, that does not depend on signal measurements.

- Ching-Fan Sheu, *DePaul University*, **Applying Bayesian Methods in psychological research**.

  The routine use of Bayesian methods in psychological research has been hindered by the absence of efficient algorithm for the calculation of posterior distributions. Recent advances in Markov Chain Monte Carlo techniques has been shown to have great potential for the analysis of models with complex structure.

  In this paper I will discuss three examples of the use of Gibbs sampling in analyzing models of psychological data: a mixture model in the development of temperament, a random effects model for combining and comparing estimates of effectiveness of diagnostic tests, and a graphical network model. These analyses are carried out using a program called BUGS.

1:30PM: MULTIDIMENSIONAL SCALING, STRUCTURAL EQUATION MODELING

- Mark Steyvers and Peter A. Wood, *Indiana University*, **Elbowing out the "elbow" method: A Modified cross-validation technique for determining MDS dimensionality**.

  We propose a modified cross-validation (CV) technique for determining the appropriate number of dimensions of a multidimensional scaling (MDS) solution. We choose the dimensionality that most often leads to the best generalization to proximity data from other subjects. Specifically, the computed distances from each of K dimensionalities of MDS solutions for each of N subjects are compared to the observed proximities of each of the N-1 other subjects using Spearman's rank-order correlation as the test-statistic. For each of the $N(N-1)$ comparisons, we count the number of times each dimensionality leads to the highest correlation and choose the dimensionality with the highest count. This differs from traditional CV techniques that average the test statistics across the different splits

and then choose the model with the highest average value. We compared the performance of our technique with the standard (but highly subjective) "elbow" method using both simulated and real data sets. For the simulated data sets (for which the dimensionality is specified in advance) our technique chose the correct dimensionality significantly more often than did the "elbow" method. For the real data sets that we have examined, the dimensionalities indicated by our technique corresponded with the dimensionalities interpreted or assumed by the researcher.

- Yuri Tada and Elke U. Weber, *The Ohio State University*, **Categorization and the nature of its multidimensional scaling solutions**.

  Object sorting has a well-established place as a data-gathering technique for investigating a variety of cognitive, developmental, and perceptual phenomena (e.g., Bruner, Goodnow & Austin, 1956; Rosch, 1977). The sorting method is advantageous compared to other more traditional data collection methods (e.g., see Torgeson, 1958) for multidimensional scaling, especially when the number of stimuli to be scaled is large. This is because participants can make judgments about the entire set of objects in a relative short time, thus, avoids severely taxing participants' motivation.

  Our descriptive meta-model of decision mode selection utilized multidimensional scaling technique to arrive at the important features that influence the selection of decision strategies and thus, subsequent choice in a decision situation. Monte Carlo study was conducted to examine the stability of the solution using four different aggregation techniques available for the sorting data: 1) the basic distances (without weighting), 2) weighting the distances by the size of the category 3) weighting the distances by the inverse of the size of the category, and 4) information theoretic measure (Coxon, 1982). The effect of the number of stimuli on the resulting configuration was also determined. Such finding is important to models based on categorizations, and the results provide guidelines in the use of sorting method in multidimensional scaling.

- Teresa A. Treat, David B. MacKay, Robert M. Nosofsky, *Indiana University*, **Probabilistic scaling: Basic research and clinical applications**.

  This talk reports new basic research findings and a novel clinical application using PROSCAL, a probabilistic scaling program developed by MacKay and Zinnes (1981) and recently generalized by MacKay (1998) to allow estimation using the city-block metric and simple measurement models. Using a stimulus set of 9 circles with embedded lines resulting from a factorial combination of radius size and line orientation, Ashby and Lee (1991) demonstrated that perceived orientation depends on radius, such that perception of line orientation is noisier when radius is small. They also showed that GRT, which explicitly represents perceptual variability, outperformed the MDS-Choice Model, which assumes a nonvariable percept. This raises the possibility that a probabilistic scaling approach might capture subject behavior in this type of situation well. Thus, the present study examines PROSCAL's performance and juxtaposes it with that of a deterministic scaling algorithm in an analogous situation, in which the nine distribution centroids are highly discriminable but the variance structure is constructed such that all radius variances are small but orientation variances increase as radius decreases. The second part of the talk will use PROSCAL to examine alcohol's effects on men's perceptions of women's affect and physical exposure. As most heterosexual date rapes occur while the man is intoxicated, it is important to examine possible alcohol-induced changes in stimulus configurations and variances. We compare both in groups of undergraduate males who consumed differing amounts of alcohol and then rated the similarity of all possible pairs of 14 photos of women.

- Andreas Klein, *J.W.Goethe University Frankfurt*, **The LMS Method for SEM with latent interaction effects**.

  The LMS (Latent Moderated Structural Equations) estimation method has been specifically developed for the ML estimation of latent interaction effects (Klein & Moosbrugger, 1998). In a structural equation, the latent variables are usually linearly related, that is, the latent endogenous variables are linear functions of the latent exogenous variables. But in some cases theory may suggest that the effect of a latent exogenous variable on a latent endogenous variable is itself moderated by a second exogenous variable. Then, in addition to the linear effects, a latent interaction effect becomes part of the latent model structure. The interaction effect is implemented by including a product of latent exogenous variables in the structural equation. More

general, latent interaction models involve nonlinear structural relationships including one or several products of exogenous variables in the structural equation. In the LMS method, a stochastic analysis represents the non-normal distribution of the indicator variables as a finite mixture of normal distributions. LMS provides efficient parameter estimates and yields unbiased standard error estimates for inferential statistics. It outperforms alternative methods, e.g. LISREL or 2SLS, with regard to efficiency, statistical power, and the capability of detecting latent interaction (Schermelleh-Engel, Klein & Moosbrugger, 1998). The paper discusses the features of LMS relevant for application to empirical data and illustrates this by an empirical example. Conclusions for the application of interaction models under the methodological demands of social science are drawn.

- Leticia T. Postrado, Lisa B. Dixon, Janine C. Delahanty, Scot W. McNary, Jack E. Scott, *University of Maryland, Baltimore*, **Evaluation of the health belief model in predicting medication compliance among persons with schizophrenia: An application of structural equation modeling**.

  The objective of this paper was to evaluate the Health Belief Model (HBM) in predicting medication compliance among persons with schizophrenia. A stratified random sample of 719 persons with schizophrenia from two states were surveyed. Among others, the survey determined patients' compliance with medication, perceived mental health, perceived threat of a mental health disease, perceived helpfulness of medication, problems with medication, and scores on psychotism. A causal model based upon the HBM was developed and tested using Structural Equation Modeling (SEM). The hypothesized model was assessed separately on persons who were high and low on psychotism. It was expected that more support for the HBM will be found in the low group due to less cognitive impairment. Maximum likelihood method of analysis rejected the hypothesized model in both groups. Revisions and alternative model testing yielded a final model that best fit the data for each group. As expected, the data for the low group was more consistent with the HBM than those of the high group. For the low group, perceived susceptibility to mental illness, perceived benefits, and perceived barriers had significant direct effects ($p < .05$) on compliance with medication. More research is needed to test the final model on a different sample.

3:30PM: PLENARY TALK

- Lotfi A. Zadeh, *University of California, Berkeley*. **Toward a computational theory of perceptions**.

  Humans have a remarkable capability to perform a wide variety of physical and mental tasks without any measurements and any computations. Familiar examples of such tasks are: parking a car, driving in heavy traffic, playing golf, assessing wine, recognizing distorted speech and summarizing a story.

  Underlying this capability is the brain's crucial ability to manipulate perceptions-perceptions of distance, size, weight, time, force, color, direction, number, similarity, intent, likeli hood and truth, among others.

  One of the basic aims of science has been and continues to be that of progressing from perceptions to measurements. Pursuit of this aim has led to brilliant successes. We have sent men to the moon; we can build computers that are capable of performing billions of computations per second; we have constructed telescopes that can explore the far reaches of the universe; and we can date the age of rocks that are millions of years old. But alongside the brilliant successes stand conspicuous underachievements and outright failures. We cannot build robots which can move with the agility of animals or humans; we cannot automate driving in heavy traffic; we cannot translate from one language to another at the level of a human interpreter; we cannot create programs which can summarize nontrivial stories; our ability to model the behavior of economic systems leaves much to be desired; and we cannot build machines that can compete with children in the performance of a wide variety of physical and cognitive tasks.

  It may be argued that underlying the failures is the unavailability of a methodology for reasoning and computing with perceptions rather than measurements. An outline of such a methodology-referred to as a computational theory of perceptions (CTP)-is put forth in our lecture.

  The point of departure in the computational theory of perceptions is the assumption that perceptions are described as propositions in a natural

language, e.g., "Michelle is slim," "it is likely to rain tomorrow," "it is very unlikely that there will be a significant increase in the price of oil in the near future." In this perspective, natural languages may be viewed as systems for describing perceptions.

To be able to compute with perceptions it is necessary to have a means of representing their meaning in a way that lends itself to computation. Conventional approaches to meaning representation cannot serve this purpose because the intrinsic imprecision of perceptions puts them well beyond the expressive power of predicate logic and related systems. In the computational theory of perceptions, meaning representation is based on what is referred to as *constraint centered semantics of natural languages (CSNL)*

A concept which plays a central role in CSNL is that of a generalized constraint. Conventional constraints are crisp and are expressed as $X \in C$, where X is a variable and C is a crisp set. In a generic form, a generalized unconditional constraint is expressed as X isr R, where X is the constrained variable; R is the constraining (fuzzy) relation which is called the generalized value of X; and isr, pronounced as *ezar*, is a variable copula in which the value of the discrete variable r defines the way in which R constrains X. Among the basic types of constraints are the following: equality constraints ($r :=$); possibilistic constraints (r :blank); veristic constraints ($r : v$); probabilistic constraints ($r : p$); random set constraints ($r : rs$); usuality constraints ($r : u$); and fuzzy graph constraints ($r : fg$).

In constraintcentered semantics, a proposition, p, is viewed as an answer to a question, q, which is implicit in p. The meanings of p and q are represented as generalized constraints, which play the roles of canonical forms of p and q, $CF(p)$ and $CF(q)$, respectively. $CF(p)$ is expressed as: X isr $?R$, read as "What is the generalized value of X?" Correspondingly, $CF(p)$ is expressed as: X isr R, read as "The generalized value of X isr R." The process of expressing p and q in their canonical forms plays a central role in constraintcentered semantics and is referred to as explicitation. Explicitation may be viewed as translation of p and q into expressions in GCL-the Generalized Constraint Language.

In the computational theory of perceptions, representation of meaning is a preliminary to reasoning with perceptions-a process which starts with a collection of perceptions which constitute the initial data set (IDS) and terminates in a proposition or a collection of propositions which play the role of an answer to a query, that is, the terminal data set (TDS). Canonical forms of propositions in IDS constitute the initial constraint set (ICS). The key part of the reasoning process is goaldirected propagation of generalized constraints from ICS to a terminal constraint set (TCS) which plays the role of the canonical form of TDS. The rules governing generalized con straint propagation in the computational theory of perceptions coincide with the roles of inference in fuzzy logic. The principal generic rules are: conjunctive rule; disjunctive rule; projective rule; surjective rule; inversive rule; compositional rule; and the extension principle. The generic rules are specialized by assigning specific values to the copula variable, r, in X isr R.

The principal aim of the computational theory of perceptions is the development of an automated capability to reason with perceptionbased information. Existing theories do not have this capability and rely instead on conversion of perceptions into measurements-a process which in many cases is infeasible, unrealistic or counterproductive. In this perspective, addition of the machinery of the computational theory of perceptions to existing theories may eventually lead to theories which have a superior capability to deal with realworld problems and make it possible to conceive and design systems with a much higher MIQ (Machine IQ) than those we have today.

4:40PM: HISTORY AND CURRENT DEVELOPMENTS RELATED TO PROBABILISTIC CHOICE AND MEASUREMENT (*Session organized by Michel Regenwetter, Duke University*)

- *Information related to the Conference and Workshop on Random Utility Theory and Probabilistic Measurement Theory can be found on the last page of the abstracts.*

- Martin Chabot, *McGill University*, **Recent work and open problems in probabilistic measurement theory**.

  The terms "characterization problem" and "representation problem" are introduced, and their various overlapping uses discussed. We also introduce three standard "representational"

frameworks for probabilistic measurement—random relations, random functions and random utilities—and show how they relate to each other. We then show how such representational frameworks relate to characterization problems, with illustrations of recent work and open problems in areas such as extensive measurement and binary choice.

- Jean-Claude Falmagne, *University of California, Irvine*, **Media theory**.

  This presentation will review published and unpublished results concerning Media Theory. Applications of media are many and diverse, ranging from convex analysis to combinatorics and political sciences. For example, the family of all strict partial orders on a finite set, equipped with the set of transformations consisting in adding (or removing) an ordered pair to (or from) a partial order to form another partial order is an instance of a medium. In general, a medium is a particular semigroup of transformations on a finite set of states. While these transformations are never one-to-one functions, to each transformation is associated a unique 'reverse' transformation undoing its actions. We require the semigroup to be transitive: any state can be transformed into any other state. Two other axioms ensure the consistency of the transformations producing a state. We introduce the concepts of 'orientation' and of 'closure' for a medium and derive some consequences. We also describe a stochastic version of a medium. In this context, a realistic application of media theory to the analysis of opinion poll data is discussed.

- Sergei Ovchinnikov, *San Francisco State University*, **Media graphs and groups**.

  A medium can be represented as a graph and there are different ways to associate a group with the medium. In this presentation we overview various discrete mathematical structures associated with media and formulate a number of open problems. An example of a typical problem is media enumeration and classification. We also introduce a representation theory for media.

- Michel Regenwetter, *Duke University*, **Probabilistic preferences, random utilities and social welfare**.

  At the heart of social choice theory lies the fact that preferences or utilities vary between observers, and therefore need to be aggregated. The present paper reconciles probabilistic ranking models and random utility models with majority rule social choice. Much research on social choice is based on the "impartial culture" assumption, according to which every preference is equally likely. In contrast, I propose to use probabilistic models as inference tools to estimate from observed ballots the distribution of preferences in actual elections. This suggests a general framework to analyze social choice in practice.

- Jun Zhang and Matthew Jones, *University of Michigan.* **Preference rank-order induced from pairwise comparisons**.

  For N distinct objects, let p_{ij} be the probability that item i is chosen over ("preferred to") item j in a binary comparison task, where $p_{ij} + p_{ji} = 1$. All such binary choice probabilities resulting from pairwise comparisons of N objects form a vector of $N(N-1)/2$ dimensions. The question is whether and if so how such pairwise preference structure, which has the geometry of a unit cube of dimension $N(N-1)/2$, would induce a preference structure of rank-order over the entire set of N objects. The answer is "Yes," since (a) all possible rank-orders of N objects can be geometrically represented as a convex polytope in $N-1$ dimensions, the so-called "permutahedron," osculated by the $(N-1)$-ball, with its $n!$ vertices representing all possible total orders of the N items, its edges connecting adjacent vertices representing a single transposition of neighbors in a total order, and its interior representable by a linear combination of a subset of its vertices (due to the convexity of the permutahedron); and (b) there exist an affine (linear) projection, thereby preserving the topology of the preference structure, from the $N(N-1)/2$-dimensional unit cube onto this $(N-1)$-dimensional permutahedron, such that each of the n! total orders is the image of a unique vertex of the unit cube whose $N(N-1)/2$ binary choice probabilities are completely consistent with that total order. The linearity of the projection ensures that linear aggregation of preference can be consistently performed both under binary comparisons (i.e., within the unit cube) and under rank-orders (i.e., within the permutahedron). We derive the constraints on the binary choice probability vector mapping onto O, the center of the permutahedron, a point indicating an absence of any trend ("strength") for rank-ordering preference. Define c_i as the average of all binary choice proba-

bilities between an item i and the $N-1$ remaining items: $c_i = \sum_j p_{ij}/(N-1)$. The binary choice vectors mapping onto O (and thus carrying null strength for rank ordering) satisfy: $c_i = 0.5$ for all i. When $N = 3$, this condition reduces to: $p_{12} = p_{23} = p_{31}$, the tri-cyclic condition. Note for $N > 3$, such cyclic preference over N items is *not* a sufficient condition for the lack of strength in rank ordering.

4:40PM: STRUCTURE IN PERCEPTION AND MEMORY

- Geoffrey J. Iverson and Stefania Za, *University of California, Irvine*, **Why ratios of cone excitations are almost invariant under daylights**.

  It is known that ratios of cone excitations are very nearly invariant for surfaces lit by blackbody radiators and daylights. The literature does not however explain why this is so. We shall explain. Implications for the phenomenon of "color constancy" are immediate.

- Helena Kadlec, *University of Victoria*, **Emergent properties as perceptual interactions in the General Recognition Theory**.

  Two types of emergent properties are defined within the General Recognition Theory (GRT; Ashby & Townsend, 1986). One type of emergent property is defined as a new qualitative property that emerges from information processing occuring across levels of structural organization; the second type appears from the processing of stimuli at subsequent stages of information processing. Each type is related to components of the dynamic version of GRT, and both are linked to the two definitions of perceptual independence that exist within GRT (i.e., perceptual separability, PS, and perceptual independence, PI). Several emergent properties, selected from Gestalt laws of perceptual grouping (i.e., symmetry and grouping by proximity), are examined from this perspective. Theoretical considerations indicate that symmetry is a property that emerges across levels of structural organization, leading to predictions that PI will fail in symmetric stimuli, whereas PS is expected to hold. Similarly, perception of horizontal or vertical rows of many smaller elements, formed by their specific arrangement via the law of perceptual grouping by proximity, is predicted to be a perceptual property emerging across levels of organization, leading to failures of PI in stimuli where the grouping occurs but not where grouping does not occur. Preliminary empirical results indicate that these hypotheses are supported.

- Thaddeus M. Cowan, *Kansas State University*, **Classification of figural ambiguities**.

  At last year's meeting, I presented a topological analysis of figure ambiguity which generated new types of ambiguities. This year's paper looks at how ambiguities can be classified. The first classification follows symmetry group transformations (e.g., rotation: Verbeek's "Topsy-turvies," translations: Dali's "Voltaire in the slave market," etc.). This does not come from the topology. However, the second classification falls out of the topology and includes simple, complex, and hypercomplex figures. These vary in the number (and types–to be explained) of interpretations a given ambiguous figure possesses. One hypercomplex figue is very simple in composition but offers six interpretations or 15 ambiguities (six interpretations taken two at a time). An attempt will be made (maybe) to relate the two (if I can think of a relationship between now and August).

- Michael J. Wenger, *University of Notre Dame*, **An initial exploration of the holistic encoding hypothesis: Model and data**.

  In a recent elaboration of a reasonably long-standing hypothesis, Farah, Wilson, Drain, and Tanaka (1998) suggest that faces (as visual stimuli) are encoded, maintained, and used in cognition as "undifferentiated wholes" to an extent that distinguishes them from other visual forms. Various ways in which this hypothesis can be represented using linear dynamic systems augmented with stochastic components (based on work by Townsend & Wenger, 1998) will be presented, in the specific context of a recognition memory task, along with data from an initial experimental test of these predictions.

- **Saturday, 31 July**

8:00AM: SPECIAL SYMPOSIUM ON LEARNING MODELS (*Session organized by Dan Friedman, University of California, Santa Cruz)*

- Ed Hopkins, *University of Edinburgh*, **Two competing models of how people learn in games**.

Reinforcement learning and stochastic fictitious play are apparent rivals as models of human learning in games. Some economic theorists have been dismissive of reinforcement models as being simply too naive to describe human learning behaviour. In contrast, Erev and Roth (1998) find that experimental data is better explained by reinforcement learning that than a form of fictitious play, while Camerer and Ho (1999) claim that an intermediate model gives the best fit. This paper takes a different but complementary approach. The theoretical properties of reinforcement learning and stochastic fictitious play are compared. To do this, new results on both models are developed, using results from the theory of stochastic approximation. The surprising thing is that despite their very different fundamental assumptions about what information agents use and how they use it, for two important classes of games, zero sum games and games of identical interest, their long run behaviour is identical.

- Ido Erev, *Technion*, Al Roth, *Harvard University*, Greg Barron, *Technion*, and Robert Slonim, *Case Western University*, **On the value of incorrect learning models: The human power measure**.

  Experimental study of decision making in repeated tasks reveals robust behavioral regularities that can be captured by relatively general models. For example, Erev and Roth (1998) show that simple learning models provide a good approximation of behavior in 12 matrix games even without fitting parameters to individual games. The suggestion that the parameters can be stable across games is important because it implies that these models can be utilized to provide useful ex-ante predictions of behavior in new tasks.

  However, traditional statistical analysis reveals that the optimistic hypothesis of a general set of parameters can be rejected. The current research argues that the fact that simple and general learning models are incorrect (can be rejected), does not imply that they are not useful. We suggest that the usefulness of a model can be estimated by the size of the experiment that has to be run to derive predictions that are more accurate than the model's predictions. The number of subjects that have to be run is referred to as the "human power" of the model. It turns out the human power measure is inversely related to Cohen's (1986) d measure of effect size. Analysis of experimental results reveals that in a wide set of situations, incorrect learning models can have high human power.

- Dale O. Stahl, *University of Texas, Austin*, **Rule learning in symmetric normal-form games: Theory and evidence**.

  An experiment, consisting of two 15 period runs with 55 games, was designed to test Stahl's (1998) model of boundedly rational behavioral rules and rule learning for symmetric normal-form games with unique symmetric Nash equilibria. A player begins with initial propensities on a class of evidence-based behavioral rules, and given experience over time adjusts her propensities in proportion to the past performance of the rules. The experimental data provide significant support for rule learning and heterogeneity characterized by three modes. We also strongly reject "Nash learning" and "Cournot dynamics" in favor of rule learning.

- Patrick Suppes, *Stanford University*, **Problems and potential of machine learning**.

  This talk will examine what stands in the way of rapid progress in machine learning for computers and what are the prospects in the near future. Various results will be surveyed, from chess as perhaps the most successful program to the failure to have as yet really smart language-learning programs, in spite of many partial results of some interest. The relevance of machine learning to achieving many desired technological goals will also be analyzed.

- Hugh Kelley, *Indiana University*, **What can we gain with more psychologically based models of decision making?**

  A recurring controversy within the experimental economics and psychology literatures concerns what model qualifies as the "best" representation of the individual decision making process. Even the definition of best is debatable, but one might expect that a good model would allow the modeler to gain more psychologically realistic assumptions about individual information processing abilities while simultaneously providing more accurate forecasts of their responses. Many economists suggest that variations of the Bayesian approach can fairly well predict human behavior, with notable systematic deviations. The psychological criticism of this approach is that perhaps it attributes information processing abilities to agents that may

not be psychological justifiable; namely it implies the ability to do complex matrix operations with potentially long sequences of information in ones head. Psychologists, on the other hand, suggest that more cognitively based models incorporating realistic assumptions about memory and attention are a truer description of the information integration process. One would expect that models that are a more accurate reflection of the decision making process should generate at least as accurate predictions as the somewhat ad hoc Bayesian model. In an attempt to shed additional light on this discussion a model comparison is provided. Two versions of a Bayesian model, one incorporating memory and recency effects with optimized rolling regression methodology, are compared with the more psychology based delta learning rule, the ALM model of Busemeyer and Roe, and the rapid attention shifting RASHNL model of Kruschke and Johanssen. All models are fit to a common training block of data from various individual choice experiments and are used to forecast subject's responses over a common forecasting block. The performance of the models is rated by comparing forecast accuracy and R^2s over the forecasting block.

- Nicole Marie Bouchez, *University of California, Santa Cruz*, **Learning models in a three by three bimatrix world**.

  This paper uses a series of laboratory experiments with 8 to 20 profit motivated players to look at different learning models including the Camerer and Ho (1998) EWA model, belief learning and reinforcement learning models. Players play against the mean action of their opponents in an information environment where they can see their opponents' actions but do not know their opponents' payoff matrices. Both single populations games and symmetric and asymmetric two population games are used.

- David Helmbold, *University of California, Santa Cruz*, **An introduction to boosting**.

  Freund and Schapire's AdaBoost is an elegant algorithm from the computational learning theory community that has proven practical benefits. This algorithm boosts the performance of an arbitrary learning method by calling the method on different distributions over the training set and combining the results. The talk will start by outlining the AdaBoost algorithm and its learning theory context. It will then mention some prominent applications and discuss the geometric intuition behind AdaBoost and related algorithms.

8:00AM: INFORMATION PROCESSING II

- Peter R. Killeen and Scott Hall, *Arizona State University*, **Absolute response strength**.

  There is no agreement on a standard measure of response strength, the "state of the reflex with respect to all its static properties," although it is often associated with response rate, latency, probability, and persistence. The relationship of those dependent variables to one another and to the passage of time was analyzed by probabilistically reinforcing pigeons' key-pecking during a trials procedure (10-s on, 10-s off). Response latencies conformed to a Gumbel distribution, whose parameters were relatively invariant with changes in probability of reinforcement. Interresponse times conformed to a shifted-exponential or "Palya machine;" lack of lag-1 negative-autocorrelations ruled out a McGill/LaPlace machine. Sequential trial probabilities conformed to a 2-state Markov process. A factor analysis of probability, latency, and rate identified a single component that was highly correlated with overall response rate. The exact form of the relation between probability and rate is proportionality at low rates, exponential-integral over the full range, with correction necessary for refractory periods at the highest rates.

- Ehtibar N. Dzhafarov, *Purdue University* and Hans Colonius, *University of Oldenburg*, **Fechnerian metrics, Fullerton-Cattell principle, and Thurstonian link: Further developments in solving the oldest problem in psychology**.

  Fechnerian (subjective) distances among stimuli in a multidimensional continuous stimulus space are derived from local discriminability measures according to the theory proposed by Dzhafarov and Colonius (1997, 1999). This theory is further developed in three directions. (1) We treat Fechnerian metrics as internal metrics defined by indicatrices that are geometrically similar to the contours of the horizontal cross-sections of the discrimination probability functions made "just above" their minima. The shape of these contours may be arbitrary, even non-convex. The Fechnerian metrics therefore are generalized Finsler metrics. (2) We apply this theory to the

special case where the probability of discriminating any two stimuli is assumed to be a function of some distance between them (Fullerton-Cattell principle). If this distance is internal, then it is the Fechnerian distance. If this distance is not internal, and if the Fechnerian metric exists, then some monotonic transformation of this distance should coincide with the Fechnerian metric in the small. (3) We relate the Fechnerian metrics to the Thurstonian scheme of discrimination, according to which two stimuli are discriminated if their random representations in a perceptual space are separated by more than a critical distance. The perceptual space is assumed to be homogeneous, in two respects: all the indicatrices in this space are shifted replicas of each other (i.e., the internal perceptual metric is Minkowskian), and the distributions of the random representations of stimuli are shifted replicas of each other. If such a Thurstonian scheme holds, then the Fechnerian metric of the stimulus space is Riemannian. The Minkowskian metric of the perceptual space then can always be made Euclidian and the distribution of the random representations radially symmetrical.

- Roger Ratcliff, *Northwestern University*, and Philip L. Smith, *University of Melbourne*, **Comparing stochastic models for reaction time**.

  We examine the ability of four of the more common stochastic models for two-choice reaction time to account for data from two experiments. We also examine the mimicking properties of the models. Early results show that the Poisson counter model (Townsend & Ashby, 1983) and the accumulator model (Smith & Vickers, 1988) produce similar predictions while the constant drift diffusion model (Ratcliff, Van Zandt, & McKoon, 1999) and the Ornstein Uhlenback diffusion model (Smith, 1995) produce similar predictions. When we allow these models to have variability in criteria and in drift rate (or the equivalent), we find mimicking between the OU model and the constant drift over a wide range of paramter values that correspond to those obtained in fits to experimental data. In general, the OU and constant drift diffusion models accounted for the shapes of reaction time distributions, accuracy, and error reaction times quite well, while the Poisson counter and accumulator models predicted reaction time distributions that were too symmetrical and they each had trouble fitting the relatively fast errors at high levels of discriminability.

- James T. Townsend, *Indiana University*, and Michael J. Wenger, *University of Notre Dame*, **Hazard functions for cumulative distribution functions: Definition, properties and a capacity function for exhaustive (AND) RT experiments**.

  A new type of hazard function, based on CDFs rather than survivor functions, is proposed. The integrated version is likewise analogous to the traditional integrated hazard function. Just as the traditional integrated hazard function leads to a useful capacity function in the case of minimum-time (i.e., race = OR) processing, the new integrated hazard function permits derivation of a novel capacity function that is appropriate for exhaustive processing experiments.

- Julie Epelboim and Patrick Suppes, *Stanford University*, **Scanpath-based model of visual working memory in geometry**.

  The Oculomotor Geometry Reasoning Engine (OGRE) was proposed to model eye movements and visual working memory during problem solving in geometry. OGRE postulates that the information derived from the geometry diagram is added to visual memory (VM) using eye movements. Newly-added information overwrites information already in VM. The model was tested by recording eye movements and spoken protocols of 3 subjects (2 experts and 1 non expert) as they solved geometry problems posed with diagrams. Subjects used highly redundant eye movement patterns with multiple re-scans of the same diagram elements. OGRE's model of visual memory provided a good fit for the observed distribution of times between re-scans. The model was used to estimate the capacity of visual memory.

- Peter J. Kwantes and D. J. K. Mewhort, *Queen's University*, **A model for naming words from print**.

  We describe a computational model for representation and retrieval from the lexicon and show that it can accommodate (a) word-frequency effects, (b) the interaction of word frequency with spelling to sound regularity, and (c) effects of neighborhood size in both naming and lexical-decision tasks. Although it does not represent syllable or like units, the model also predicts that both performance in naming and lexical decision tasks should be sensitive to such structures. In addition to reading words, the model

predicts how subjects will pronounce a nonword with more than one plausible pronunciation.

- Garrison W. Cottrell, Matthew N. Dailey, *University of California, San Diego*, Curtis W. Padgett, *Jet Propulsion Laboratory, NASA*, and Ralph Adolphs, *University of Iowa*, **A simple model of categorical perception of facial expression**.

  In recent years, results consistent with "categorical perception" of higher level stimuli such as faces and facial expressions have been reported in the literature. The results on facial expression have been seen as being at odds with multidimensional accounts of facial affect perception, such a Russell's "circumplex" model. We present a simple model that accounts for the expression data (on practically the same stimuli as presented to human subjects), and is also consistent with the circumplex model. Our account is consistent with previous accounts, such as Massaro's, that categorical perception is easily explained as a decision stage imposed on a classification system that is essentially continuous

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10:50AM: YOUNG INVESTIGATOR AWARD

- Robin D. Thomas, *Miami University of Ohio*, **Can one study perceptual interactions in a comparison task? Some theory, some data, and some controversies**.

  Over the last ten years significant progress has been made in understanding how dimensions of an object interact during perception. Much of that progress has been of a theoretical nature in the defining and relating of concepts to observable data from various tasks. The present work reviews one of these developments in which the comparison or matching task is studied as one window into dimensional separability and interactivity. Theoretically, the same-different judgment task is capable of revealing similar kinds of insights into perceptual processing as other tasks such as classification and identification. In addition, two experiments reported here seem to provide support for the theoretical results and shed some light on previously controversial findings. However, some recent data from spatial vision may provide limitations related to physiology of the matching task's utility.

1:30PM: MEMORY

- Richard Schweickert, Shengbao Chen and Matthew Gozo, *Purdue University*, **Constructing a binomial tree via selective influence**.

  Performance in memory tasks is often modeled with multinomial trees. We consider binary trees in which responses can be classified into two categories. In recall, for example, responses can be classified as correct or incorrect. A probability is associated with each branch of the tree. Suppose one experimental factor selectively influences one branch probability while another experimental factor selectively influences another branch probability. Then certain relationships must hold in the data. Further, if those relationships hold in the data, a binary tree can be constructed in which each experimental factor selectively influences one branch probability. The form of the relationship indicates whether the probabilities are associated with branches on a path from the root to a terminal vertex or not on such a path. Finally, there is a set of standard trees with the following property. Given a binary tree in which the two experimental factors selectively influence branch probabilities, the given tree is equivalent to one of the standard trees.

- Xiangen Hu and Richard McCowen, *The University of Memphis*, **Statistical analysis of GPT models: From the point of view of traditional statistics**.

  Statistical issues on GPT models are examined from the point of view of traditional statistical models. The nonlinear nature of GPT models makes it problematic to answer statistically oriented questions from the traditional statistical point of view. In this talk, issues such as interactions in a factorial experiment, planned and post hoc comparisons of contrasts, robustness, and power calculations are examined. Examples drawn from literature and results from simulations will be used. We make specific suggestions on how to use GPT models to draw statistically sound conclusions.

- Bennet Murdock, *University of Toronto*, **A hierarchical pre-model for serial recall**.

  There are over 100 years of work on serial recall and still no generally-accepted explanation. Most models of serial-order effects in short-term memory are two-factor models with one factor

for primacy and one factor for recency. A simple hierarchical pre-model is developed which only assumes a particular chunk-size distribution and a set of recall probability functions for recall given chunk size. It makes predictions about run-length functions for different list lengths and the memory-span function. It does not make predictions about errors, distance functions, conditional-probability functions, or serial-position curves, but perhaps it could be extended. It can generate primacy and recency effects. Strengths and weaknesses will be discussed.

- Marc Howard and Michael J. Kahana, *Brandeis University*, **A distributed representation of temporal context**.

  The dynamics of free recall illustrate two basic principles of episodic memory performance, the principle of recency and the principle of contiguity. Experimental work has shown that these principles hold over long and short time scales (Kahana, 1996; Howard & Kahana, in press). Previously we showed that variable context can account for these two basic principles if successful retrieval of an item retrieves the context it was associated with at study. We present a model of temporal context in which contextual retrieval is a natural outgrowth of the same process of path integration that gives rise to contextual drift. The model is applied to serial position effects in free recall and paired associate learning, providing an alternative heuristic for explaining dissociations in the serial position curve. The representational properties of temporal context are also discussed.

1:30PM: DECISION, JUDGMENT, AND CHOICE

- Valerie M. Chase, *Max Planck Institute for Human Development*, **Where to look to find out why: Ecological and bounded rationality in causal hypothesis testing**.

  Many experiments suggest that people seek data that confirm their hypotheses while neglecting disconfirmatory information. Specifically, given hypotheses such as "If P, then Q," people condition their tests most often on P, then Q, and only rarely on not-Q and not-P. Some theorists have shown how this pattern could result from a positive-testing strategy that maximizes expected test diagnosticity when $p(P)$ and $p(Q)$ are rare and $p(P) \leq p(Q)$. They propose that these probability conditions are representative of real-world environments and the strategy thus ecologically rational; confirmation bias appears only in unusual (or artificial) situations. Extending this type of analysis to causal hypotheses, I investigated whether people consistently overgeneralize this strategy to conditions where its probability assumptions fail, which they often do for causal hypotheses (e.g., "eating fatty foods causes heart attacks"). I predicted that people choosing between hypothesis tests in causal selection tasks would adapt their strategies to variations in $p(P)$ and $p(Q)$ as required by a Bayesian analysis. The results of two experiments in which $p(P)$ and $p(Q)$ were varied support the prediction. Not only did participants choose more diagnostic over less diagnostic tests, but they were sensitive to the size of the difference between tests' diagnosticities as expressed in terms of log likelihood ratios weighted by prior probability distributions. Need we therefore impute boundedly rational hypothesis testers with the ability to perform the complex computations of this analysis? Fortunately not: I demonstrate that much simpler heuristics for computing expected diagnosticity converge on normative measures under many conditions.

- Rahul M. Dodhia, *Columbia University*, Geoffrey, F. Miller, *University College London*, and David H. Krantz, *Columbia University*, **Judgments of likelihood evidence**.

  We investigated the psychophysical relationship linking judged evidence strength to numerical likelihood functions and to other related forms of evidence. The likelihood functions studied had just two values, which were usually given as conditional relative frequencies, $Pr(x|H)$ and $Pr(x|\text{not-}H)$.

  Study I demonstrated that, for a majority of judges, evidence strength is not a single-valued function of the ratio: holding the ratio constant, evidence strength decreases as the two Pr values decrease. Study II replicated this effect and showed that the drop in evidence strength for low Pr values is not much changed when good reasons are given for the low values. The same pattern of results was obtained even when probabilities were given as verbal categorical descriptions rather than as percentages. Study III showed that evidence judgments for pseudo-likelihoods of the form $Pr(x|H)$ and $Pr(y|\text{not-}H)$ differ little from judgments for true likelihoods.

  These results suggest a natural inference schema according to which observing x counts as evi-

dence against H, when $Pr(x|H)$ is low. This schema can, of course, lead to very poor inferences if not properly hedged by considerations of the base rate for H, the typicality of x, and the prediction specificity of H and alternative hypotheses; but it also has distinct advantages, compared with the likelihood principle.

- Richard W. J. Neufeld, *University of Western Ontario*, **Quantitative schemata of decisional stress-control**.

  This paper presents formally-derived properties of a prominent form of coping with stress known as "decisional control." Decisional control entails positioning oneself in a multifaceted situation of potential stressors so as to engage the situation component where threat is minimal. Substantive inferences are derived from generic hierarchical layouts with potential real-life parallels, where elements of situations are nested in element-sets (e.g., interpersonally-threatening individuals are nested in social gatherings; jeopardous task assignments are nested in job locations). Expression of decisional-control information-processing demands, and threat-reducing payoff with demand-fulfillment, in terms of rudimentary combinatorics and set theory reveals the interplay between these variables to be potentially complex, but tractable. Moderating effects of control-relevant information on potential benefits of this form of coping are explicated. Finally, implications for individual differences in predilection to decisional control, and empirical support for invoked assumptions, are considered.

- Barbara Mellers, *The Ohio State University*, **How anticipated emotions influence choice**.

  People often anticipate how they will feel about the outcomes of decisions and use those feelings as guides to choice. We explore the emotions associated with monetary outcomes of gambles, and show that these emotions depend on outcomes, expectations, and counterfactual comparisons. We provide a formal account called decision affect theory. We then investigate the effects of emotions on choice by exploring how choices depend on assumptions about unchosen options, feedback about unchosen options, contextual effects, and sequential effects. When it comes to gambles, people do not tend to select options that maximize their pleasure, minimize their pain, or minimize their regret. Instead, they appear to trade pleasure off against pain and select options that maximize their subjective expected pleasure.

- Jeff T. Larsen, A. Peter McGraw, and Barbara A. Mellers, *The Ohio State University*, **Disappointing wins and relieving losses: The agony of victory and the thrill of defeat**.

  Decision affect theory (Mellers et al., 1997) describes emotional reactions to risky outcomes as a function of the obtained outcome, a comparison between the utility of the obtained and unobtained outcomes, and the surprisingness of the obtained outcome. The theory predicts that people do not feel as good about a given win when it is the worse of two possible wins (a disappointing win), than when it is the better of two possible wins. Likewise, they do not feel as bad about a given loss when it is the better of two possible losses (a relieving loss), than when it is the worse of two possible losses. The current research examined whether disappointing wins and relieving losses elicit ambivalence (i.e., both good and bad feelings), rather than simply attenuating good and bad feelings, respectively.

  In three studies, participants rated their emotional reactions, ambivalence, positive feelings, and negative feelings to the outcomes of hypothetical monetary gambles. In Study 1, disappointing wins elicited more ambivalence than non-disappointing wins, and relieving losses elicited more ambivalence than non-relieving losses. Ambivalence elicited by disappointing wins and relieving losses was directly related to the size of the unobtained outcome (Study 2) and to the surprisingness of the obtained outcome (Study 3).

  Results suggest that treating emotion as the net difference between good and bad feelings may fail to capture people's emotional reactions to disappointing wins and relieving losses. Implications for models of emotional reactions will be discussed.

3:30PM: PLENARY TALK

- Patrick Suppes, *Stanford University*, **Language and the brain**.

  This talk will cover research I have been doing on brain-wave recognition of words, sentences and visual images using EEG recordings. The emphasis will be on the recent unpublished results.

These support the invariance of brain-wave representations of language between subjects and between words and visual images. The most recent work concerns the representation of the brain waves of words by a small set of fundamental frequencies, all usually less than 20 Hz. The final part will be on possible future developments using ever more detailed models of the electric fields generated by populations of neurons.

4:40PM: MODEL EVALUATION AND SELECTION

- Dominic W. Massaro, *University of California, Santa Cruz*, **Simulation, Occam's Razor, and FLMP**.

  In a recently published paper Myung and Pitt (1997) argued that an important property of mathematical models is model complexity, which is given by the flexibility of a model in predicting points in the space of all possible data points. They proposed a Bayesian Model Selection (BMS) to adjust for model complexity and evaluated two integration models, the fuzzy logical model of perception (FLMP) and the linear integration model (LIM), using BMS and the root mean square deviation (RMSD). They concluded (a) the original models were better recovered by BMS, (b) The BMS gave a clearer indication of model superiority, (c) FLMP was more complex than the LIM because the FLMP fit LIM data better than the LIM fit FLMP data, and (d) the overall supremacy of the FLMP was due only to its flexibility in fitting small, random variations in the data. However, comparisons between BMS and RMSD were not representative of prototypical experiments because the models tested were based on asymmetrical factorial designs. Our re-evaluation of BMS and RMSD methods in symmetrical expanded factorial designs with both real data and simulated data refuted most of the conclusions of Myung and Pitt (1997) and shows that the FLMP continues to be the winner of the horse race among models of pattern recognition.

- John C. Dunn and Ralph N. James, *University of Western Australia*, **Zone analysis: A "strong inference" method of model testing**.

  A model may be represented geometrically as a low-dimensional "response surface" embedded in a higher-dimensional outcome space. Data correspond to points in this space and model fit is evaluated by the total minimum discrepancy between such points and the response surface. The present paper introduces an alternative method of model evaluation, called zone analysis, that relies on comparisons between data points rather than between such points and the response surface. Consequently, there is no explicit error function nor requirement for parameter estimation. Zone analysis is based on the fact that the set of directions between points on a model's response surface is an identifiable subset of all possible directions in outcome space, where such directions are classified according to the zone they occupy. By definition, two directions occupy the same zone if their signs are the same. For example, the directions (a, b) and (c, d) occupy the same zone in two-dimensional vector space if $\text{sign}(a) = \text{sign}(c)$ and $\text{sign}(b) = \text{sign}(d)$. This leads to the following "strong inference" test of a model—a model is falsified if the direction between any two data points occupies a zone that is not occupied by points on its response surface. Two models of the remember-know paradigm are compared using zone analysis which is used to derive a crucial test to distinguish between them.

- Richard M. Golden, *University of Texas at Dallas*, **A model selection test for misspecified time-series models**.

  Vuong (Econometrica, 1989) proposed a large sample model selection test for comparing nonnested and nested probability models. Such model selection tests are useful for deciding which of two probability models "best-fits" the data generating process or whether both candidate probability models fit the data generating process equally well. Golden (JMP, in press) has described an extension of Vuong's (Econometrica, 1989) approach which allows one to select the "best-fitting" model on the basis of a more general model selection criterion that includes the classic log-likelihood loss criterion considered by Vuong (Econometrica, 1989) as a special case. This paper further extends the work of Golden (JMP, in press) so that observations need not be independent and identically distributed but merely stationary and ergodic.

  The main motivation for this development was to extend Golden's (1998, Discourse Processes) Knowledge Digraph Contribution theory for analyzing text recall data as a time-series of categorical variables. However, these results are applicable to many other important areas of mathematical psychology such as: model selection

for time-series models of human behavior, linear (and nonlinear) regression models where the observations at neighboring instants in time are correlated, or selecting the best artificial neural network for learning time-series data with temporal statistical regularities.

- Flip Phillips, *Skidmore College*, **A genetic methodology for high-dimensional experiments**.

  A methodology is presented for carrying out experiments in which the independent variables are of such a high dimensionality that it would be cost or time prohibitive to engage in the systematic, fully factorial manipulation of each of them individually. This methodology differs from such factorial methods in that it is derived from a genetic metaphor, where the variables are encoded as 'genes' that express themselves through an evolutionary experimental strategy. Paths through variable space that survive are bred with other fit paths, eventually (but not always) resulting in a maximally fit configuration of the variables in a practical amount of time. In fact, the accuracy / time tradeoff can be controlled to yield desirable levels of either. An example experiment is presented which demonstrates this procedure along with a discussion of the possible ramifications of its use.

4:40PM: SPECIAL SESSION ON PROFESSIONAL DEVELOPMENT *(Session organized by David J. Weiss, California State University, Los Angeles)*

- David J. Weiss and Michael W. Roffe, *California State University, Los Angeles*, **Is there an academic future for mathematical psychologists?**

  In principle, job prospects for mathematical psychologists depend on supply and demand. One might expect the supply to grow exponentially, as each professor produces a student every few years; and then the student becomes a professor and the cycle continues. Demand, however, is limited by the number of universities. This number has not increased much. In addition, forces within some departments mitigate against the proliferation of slots for mathematical psychologists. The Malthusian implications are dire. The mathematical psychology mentoring survey suggests that our community has reacted to this potential crisis by not producing as many students as one might expect.

- Michel Regenwetter, *Duke University*, **By the way, I'm on the job market**.

  I report from my own perspective what it is like to be on the job market in mathematical psychology, after having been there 4 times: first as a fresh PhD, then twice as a Post-Doc and finally as an Assistant Professor with a (spousal) dual-career issue. A serious limitation of the analysis is that it is only a case study (without a model or a statistical test) and entirely rests on a respondent sample size of N=1.

- John Miyamoto, *University of Washington*, **Mathematical modeling in medical decision making**.

  Research in medical decision making overlaps many areas of cognitive psychology. The basic conceptual framework is Bayesian, and many research problems arise in the context of attempts to provide decision analyses of specific therapy decisions. I will review different ways that mathematical psychology can contribute to this enterprise, for example, by testing models of preference and value, probability judgment, and ROC analysis. The goal of the talk will be to introduce mathematical psychologists to areas within medical decision making to which they may be able to contribute.

- **Sunday, 1 August**

9:00AM: SPECIAL SYMPOSIUM ON MODEL COMPLEXITY *(Session organized by In Jae Myung, The Ohio State University)*

- Vijay Balasubramanian, *Harvard University*, **An information geometric formulation of Occam's razor**.

  I describe an information geometric formulation of Occam's Razor which arises by viewing parametric families of distributions as manifolds embedded in the space of distributions. Making inference procedures independent of parameterizations of the manifold requires a natural measure on the model space. I derive such a measure by using the classical theory of hypothesis testing to count the indistinguishable distributions contained within any given parameter volume. The resulting measure is related to the Fisher information of the model family, and agrees in a Bayesian interpretation with Jeffrey's prior. I then derive a natural definition of the complexity of a parametric family relative to a true distribution which I will call the "razor" of a model

family. The Minimum Description Length principle and Bayesian inference are shown to give empirical approximations to the razor. Notions such as the "simplicity" and "robustness" of a particular model family are given geometric interpretations.

- Peter Grunwald, *Stanford University*, **Determining the complexity of arbitrary model classes**.

  The Minimum Description Length (MDL) Principle is a general method for inductive inference that provides a principled and well-motivated approach to the problem of model selection. It is closely related to the Bayesian-statistics approaches, yet its roots lie in Kolmogorov Complexity, a subfield of theoretical computer science and information theory rather than statistics.

  Most model selection methods are only well-defined if the model classes under consideration are *probabilistic* (i.e. all models considered are probability distributions over the possible data values). This seems quite a serious limitation of these methods.

  Here, we demonstrate the following: while judging from most existing work on MDL, the same limitation to probabilistic models seems to apply. But it really does not: we first review the idea of Kolmogorov Complexity and show how it gives rise to the notion of complexity arising in the MDL Principle. Kolmogorov Complexity is a concept that does not refer to any probabilities. We show how this implies that MDL itself can really be applied to *arbitrary* model classes—there is certainly no need for them to be probabilistic. Such model classes include non-probabilistic model classes (like classes of neural networks, for example) and qualitative model classes (sometimes even called "non-mathematical model classes"), as for example decision trees or qualitative models for decision making. We will give a detailed example of an application of MDL to such a non-mathematical model class.

- Shu-Chen Li, *Max Planck Institute for Human Development*, **complexity as parameter sensitivity and interdependence: Applications to models of perceived depth and network classifiers**.

  Previous research on digital filter structures and parameter sensitivity was extended to examine the scope of two models of perceived depth and the relationship between the nature of hidden-unit activation function and network complexity. Assuming additive Gaussian noise, parameter sensitivity is defined as the trace of the Fisher information matrix ($\mathbf{F}$) of the parameters, which is indicative of the slope of a given model's parameter space. Whereas, the condition number (k_2) of the same matrix measures the degree of co-linearity among the parameters, which is indicative of the smoothness of the parameter space. A combined measure (τ) defined as the ratio of parameter interdependence to sensitivity [i.e., ($\tau = k_2(\mathbf{F})/\text{trace}(\mathbf{F})$] is indicative of a model's scope and intrinsic computational complexity. Simulation results show that (a) model scope is inversely related to τ, and (b) the complexity of the hidden-unit activation function and the rate of convergence also relate inversely to τ. Principles underlying the sensitivity and interdependence analyses as presented here are closely related to recent works on developing algorithms for finding low-complexity networks, high error-tolerant networks, and on assessing the effective degrees of freedom of Kernel smoothers and RBF networks.

- Michael D. Lee, *Communications Division, Defence Science and Technology Organisation (Australia)*, **On the complexity of multidimensional scaling, additive clustering, and additive tree representations**.

  Multidimensional scaling, additive clustering and additive trees constitute three different, and largely complementary, representational approaches to revealing the latent structure in similarity data. In multidimensional scaling, stimuli are represented as points, so that more similar stimuli are located nearer each other. In additive clustering, stimuli are represented in terms of the presence or absence of weighted binary features. In an additive tree, stimuli are represented as leaf nodes, so that their similarity is modeled by the length of the unique path between them through the tree. Each of these representational approaches, however, raises a series of issues relating to model complexity. In terms of parametric complexity, it is often possible to improve the data-fit of a representation by adding more spatial dimensions, including more clusters, or using more internal nodes within a tree topology. This issue is addressed using the Bayesian Information Criterion (BIC), an evaluative measure that considers both data-fit and parametric complexity. Emphasis is given to the

fact that the BIC formulation developed is sensitive to the precision of the similarity data being represented. More subtle complexity effects, dependent upon the way in which parameters interact within a representation, are also considered. These relate the the form of the distance measure used in multidimensional scaling, the size and the patterns of cluster overlap in additive clustering, and the nature of the topology used by an additive tree. Using the Laplacian approximation, a detailed complexity measure for the additive clustering case is derived, and its implications considered in some detail.

- John C. Dunn, *University of Western Australia*, **Model complexity: The fit to random data reconsidered**.

  Model complexity is conceptualised as the capacity of a model to fit any conceivable data set. A model can be represented geometrically as a low dimensional "response surface" embedded in a higher dimensional outcome space in which data are represented as a point or set of points. The fit of the model to a data point is given by the minimum distance between the point and the response surface. Model complexity can thus be thought of as the extent to which the response surface is "close to" arbitrary points in outcome space. If the extension of outcome space can be assumed to be bounded, complexity can be operationalised as the mean minimum distance, defined as the average minimum squared distance between an arbitrary data point in outcome space and the model's response surface. It may also be expressed as a dimensionless quantity called the scaled mean minimum distance. For linear models, theoretical values for the scaled mean minimum distance and the variance of the scaled minimum distance can be readily obtained and compared against empirical estimates obtained from fits to random data. The approach is applied to resolving the question of the relative complexity of the linear integration model (LIM) and the fuzzy logic of perception model (FLMP), both of which have been the subject of controversy in the field of depth perception. It is concluded that the two models are equally complex.

- In Jae Myung, Shaobo Zhang, and Mark A. Pitt, *The Ohio State University*, **Rissanen complexity and minimum description length principle**.

  "Rissanen complexity" is a measure of model complexity that Rissanen (1996) recently proposed as an improved formulation of the Minimum Description Length (MDL) principle. This complexity measure is sensitive to the functional form of a model as well as the number of parameters, and further, has a theoretically well-justified interpretation in differential geometry. In this paper we demonstrate an application of Rissanen complexity to model selection in cognitive psychology. In three areas of cognitive modeling (psychophysics, information integration, categorization), two competing models with the same number of parameters but different functional form were fit to data sets generated by each model. The model recovery rates of four selection methods (MDL with the Rissanen complexity term, AIC, BIC, and ML) were compared. The results showed that MDL was superior to the other methods in recovering the model that generated the data. These results together clearly indicate that functional form must be taken into account in model selection. Furthermore, this new selection method provides a means of quantifying the relative complexity of the models being compared.

- **Discussants**: Jerome Busemeyer and James T. Townsend, *Indiana University*

9:00AM: CATEGORIZATION AND LEARNING

- Shawn Ell, F. Gregory Ashby, and Elliott M. Waldron, *University of California at Santa Barbara*, **Dynamical trajectories in category learning**.

  Category learning has been traditionally studied by examining how percent correct changes with experience. However, many qualitatively different models make identical predictions at this level of data analysis. An alternative, and more powerful, approach is to examine dynamical learning trajectories—that is, to examine how the parameters that describe the current state of the model change with experience. We describe results from a new experimental paradigm in which empirical learning trajectories are observable. In this experiment, subjects learned two categories of spatial position, and they were constrained to identify and use a linear decision bound on every trial. The dependent variables of principal interest were the slope and intercept of the bound used on each trial. Given such data, our analyses focused on four questions. (a) Does

category learning follow a process of gradient descent? (i.e., does the bound used by subjects converge on the optimal decision bound along a path that maximizes decreases in probability of error?). (b) Are the empirical trajectories continuous, or do they periodically make large jumps? (e.g., such as would be predicted by a simulated annealing process). (c) Do the step size magnitudes generally decrease with experience? (as occurs, for example, with a cooling in computational temperature). (d) Are changes in decision strategy more likely and/or more substantial on trials after an incorrect response, as compared to trials after a correct response?

- Yoella Bereby-Meyer and Gal Shamir, *Ben Gurion University of the Negev*, **A reinforcement based learning model for probabilistic discrimination learning**.

  Recently there has been growing interest in adaptive learning models as a descriptive alternative to expected utility theory. The models assume that the choice between strategies is not a result of utility calculations, but a response that is learned from experience. Favorable experiences lead to increases in the propensity to choose a strategy, whereas unfavorable experiences lead to a decrease in the propensity to choose a strategy. In a previous study we have shown that a very simple reinforcement based learning model can account for the behavior in a probability learning task under different conditions (Erev, Bereby-Meyer & Roth, in press). The current study extends this reinforcement-based learning model to a probabilistic discrimination learning task. In a series of experiments we examined the learning of the contingency of two dichotomous variables through a prediction task. In each experiment 500 stimuli that varied on two dichotomous variables were presented. In each trial participants received information about one variable and were asked to predict the other. The correlation between the variables was manipulated between groups. Feedback and reward were given after each response. Learning was slow when subjects were simply told to predict a variable. Learning became faster when the potential existence of a correlation between the variables was indicated. A revised reinforcement based learning model was able to account for these results. The implications of the present findings for modeling learning in tasks such as medical diagnostics will be discussed.

- Joachim Meyer and Sharon Zamir, *Ben Gurion University of the Negev*, **Learning and framing in timing decisions**.

  Recent years have shown renewed interest in mathematical learning models that describe the adaptive changes in decisions as a result of the outcomes of previous decisions. The question arises how this approach can accommodate the robust phenomena that were found in behavioral decision making research, such as the effects of the framing of outcomes on decisions. We conducted a series of experiments in which participants had repeatedly to decide on the timing of interventions. While the total payoff for different timings was the same for all participants, the framing of the payoff differed for different experimental conditions. Clear learning towards the optimal timing was evident in all conditions. The framing of the outcome affected timing decisions in certain conditions during the early stages of the experiment, but it rapidly ceased to have an effect after participants gained some experience with the task. The results are compared with the predictions from simulations of an exponential reinforcement-based learning model in which the framing of outcomes is modeled as differences in the initial tendencies to choose responses. The implications of these results for the integration of research from behavioral decision making and learning perspectives.

- Patricia M. Berretty, *University of Illinois, Champaign-Urbana*, **Category choice and cue preference with multiple dimensions**.

  Many natural categories vary along multiple dimensions. However, the extant literature on categorization has, for the most part, included studies involving few categories that vary along only a few dimensions. The present studies address two main questions underlying categorization with multiple dimensions. First, how well can humans perform in a supervised categorization task consisting of five categories varying along nine dimensions (where each dimension is represented as a texture—number of dots—in one of nine possible squares on a computer screen)? Second, what cues will humans choose to use if the number of cues available is restricted? Remarkably, participants not only learned to distinguish among the five categories, but they also learned to do so using only the relevant dimensions. A satisficing model of categorization (categorization by elimination) and two popular categorization models were fit to the participants' responses. Results indicate that the satisificing

model was best able to account for the majority of the participants' responses. Finally, in a cue preference task, the results showed that nearly all participants preferred to use the dimension with the greatest variance when the number of dimensions available was restricted, in accord with predictions made by the satisficing model.

- Corey J. Bohil, *University of Texas, Austin*, **Base-rates and payoffs in perceptual categorization: A review and integration of recent findings**.

  Numerous studies have examined the effect of base-rate and payoff information on performance in probabilistic categorization tasks (i.e., tasks that use overlapping normally distributed categories). The predominant finding is suboptimal performance, with observers typically exhibiting a pattern of conservative cutoff placement (i.e., decision cutoff placement that underpredicts true base-rate or payoff ratios). Although this research provides a core of important findings, there are a number of theoretically motivated variables that might affect performance, but have not been studied rigorously. Among these factors are category-level discriminabity (d' level), the presence of negative payoff matrix values, and the type of corrective feedback presented during learning. I present a review of our recent efforts to systematically explore these factors within the framework of decision bound theory by comparing observers' performance with that of the optimal classifier - that is, the hypothetical device that maximizes long-run reward (Ashby, 1992; Maddox, 1995; Maddox & Bohil, 1998). This approach allows one to model simultaneously data from different base-rate/payoff conditions, which provides a means of testing a number of interesting hypotheses. For example, whether observers combine base-rate and payoff information in the same way as the optimal classifier, and whether observers place equal weight on costs and benefits. The implications of these results are discussed.

- J. Lee Dodd and W. Todd Maddox, *University of Texas, Austin*, **Category discriminability, base-rate and payoff effects in a simulated medical diagnosis task**.

  Human categorization performance was explored in a simulated medical diagnosis task. Three category-level discriminabilities ($d' = 1$, 2, and 3) were combined factorially with 4 separate payoff matrices, and one base-rate ratio, for a total of 15 conditions. All analyses were performed at the single-observer level using a series of nested models derived from decision bound theory (Ashby, 1992; Maddox, 1995; Maddox & Bohil, 1998a, 1998b). The optimal decision criterion (β_0) from signal detection theory was identical across all base-rate and payoff conditions. Thus, the optimal classifier (i.e., the hypothetical device that maximizes long run reward) predicts identical performance across all conditions. All observers were sensitive to the base-rate and payoff manipulations, but the optimal classifier rarely provided the best account of the data. We were interested in the effect the steepness of the objective reward function (ORF) (von Winterfelt & Edwards, 1982) on the sub-optimality of the observed decision criterion (β). The results of the model-based analyses can be summarized as follows. First, the best fitting decision criterion tended to be closer to optimal when the ORF was steeper ($d' = 2$). This was confirmed by model fits applied separately to each data set, as well as by a more rigorous model test in which all data from a single observer was modeled simultaneously. Second, β values were generally farther from optimal when the cost of an incorrect response was negative (i.e., when an incorrect response led to a decrease in reward), and were closer to optimal when the cost of an incorrect response was non-negative. This second result held across all levels of discriminability (d').

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The events (and the leaders)

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Eight half-day themes: *Mathematics of nonparametric random utility models* (J.-P. Doignon, M. Koppen); *Stochastic models of preference evolution* (J.-C. Falmagne, S. Ovchinnikov); *Parametric random utility models* (H. Joe, R. Suck); *Applications to economics and management* (M. Ben-Akiva, D. McFadden); *Applications to psychology and marketing* (U. Bockenholt, J. Huber); *Applications to economics, social choice and political science* (M. Alvarez, J. Brehm, P. Pattanaik); *Probabilistic measurement theory* (H. Colonius, D. Heyer, R. Niederee); *Wrap-up discussion* (A.A.J. Marley).

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