52nd annual meeting of the society for mathematical psychology

17th international conference on cognitive modeling

program & abstracts

Palais des Congrès, Montréal

Bienvenue à Montréal!

The joint meeting of the Society for Mathematical Psychology and the International Conference on Cognitive Modeling is upon us!

Below appear the abstracts for all accepted submissions to the Annual Meeting of the Society for Mathematical Psychology. This section is automatically generated from the submission website and may not reflect recent updates, such as withdrawn contributions or changes in authorship. Abstracts for the ICCM meeting may be found via `http://iccm-conference.org/`.

Please note that physical copies of this book will **not** be printed for all attendees. Abstracts have been made available via the Eventor app and via the conference website `http://mathpsych.org/conferences/2019/schedule/`.

The organizers thank *Elsevier*, *Springer*, and the *Artifical Intelligence Journal* for their sponsorship.

Presenting your work at MathPsych/ICCM

Is it your first time at MathPsych/ICCM? Or perhaps your first time at an academic conference at all? Not to worry — you're not the only one! In this section you'll find some basic information about attending the conference. You should feel free to reach out to the Conference Chair (`joachim+smp@uci.edu`) with any and all questions.

Dress code

The conference does not have a particular dress code. Casual dress is acceptable.

Talks

MathPsych/ICCM runs on a strict 20-minute slot schedule. Each speaker is given one 20-minute slot, and every talk should fit well within that and leave 3-5 minutes for questions and answers. Session chairs will make sure that no speaker goes over their allotted time, and also that no presentation starts before the beginning of the slot. All rooms are equipped with a projector, a screen, and a cabling package, but not with a laptop. All speakers should meet at the front of the room 15 minutes before the start of their session to meet the session chair and to copy all presentations onto one

laptop. Larger rooms are equipped with a microphone and audio system. If there is a microphone, you must use it.

Posters

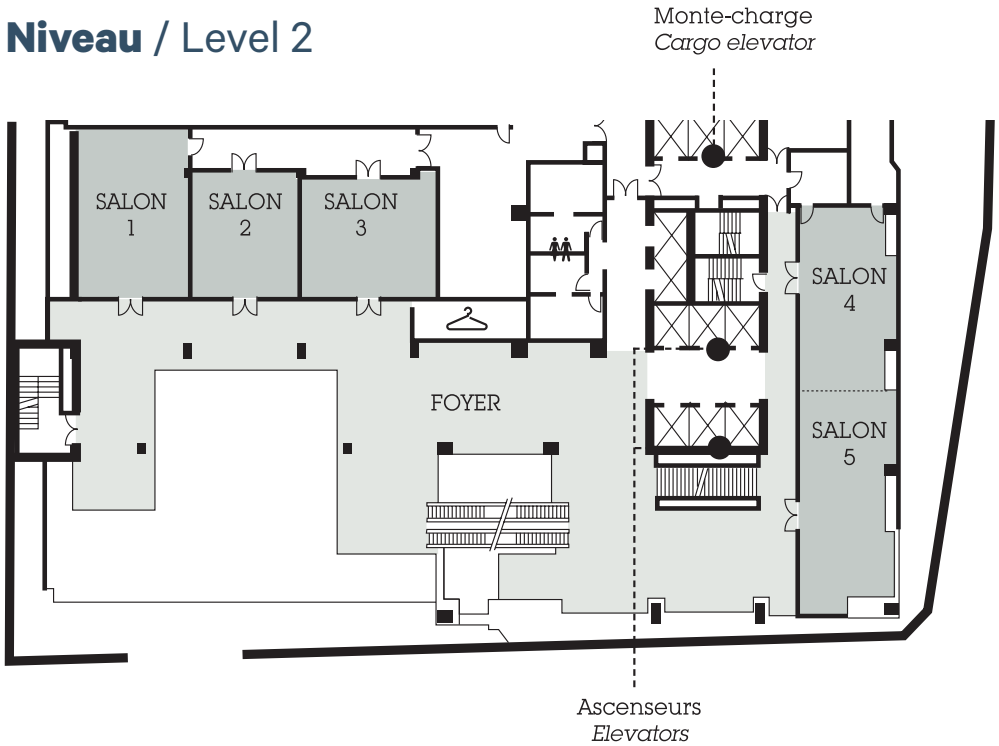
The poster session will take place in the early evening of July 20th. Presenters are asked to mount their posters around 15:00 and to attend their own posters from 17:00 until 19:00. Posters should be 4 by 4 feet (120cm by 120cm) or smaller. Posters must not be wider than 4' and should be readable from a few steps away. Posters in portrait orientation are preferred. We will provide velcro tape, pushpins, or other adhesives.

Conference Wi-Fi

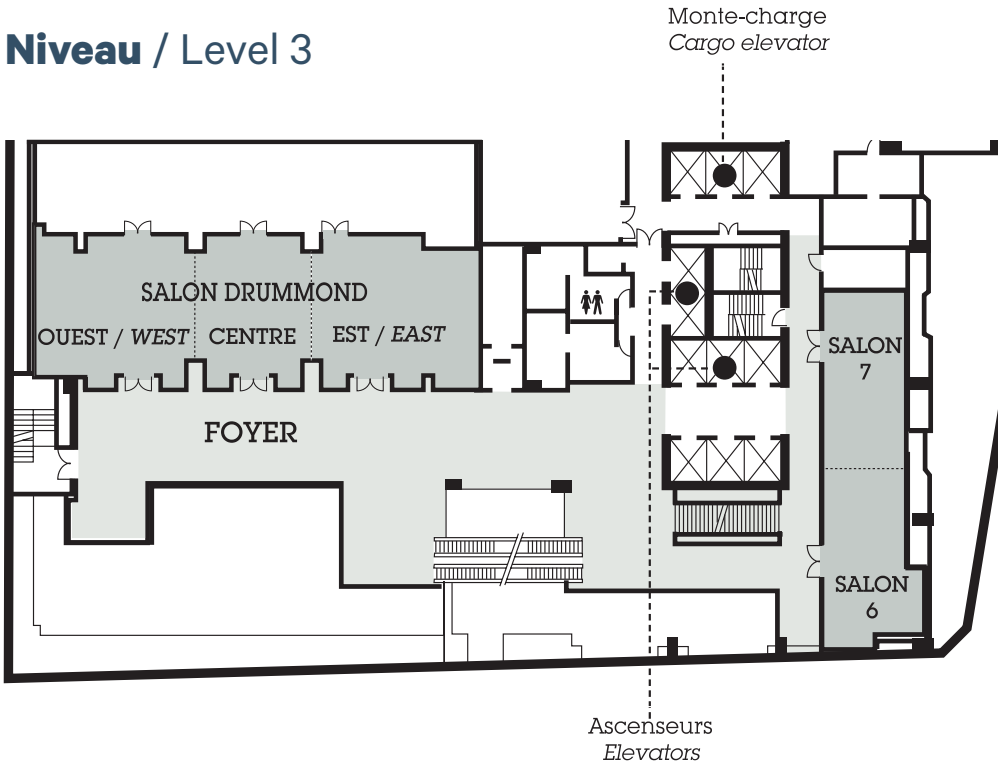
At the conference, you can access the **Sheraton_CONFERENCE** network with access code **iccmpsyched**. If you know what to do with a hashtag, it's **#iccmpsyched**.

Venue

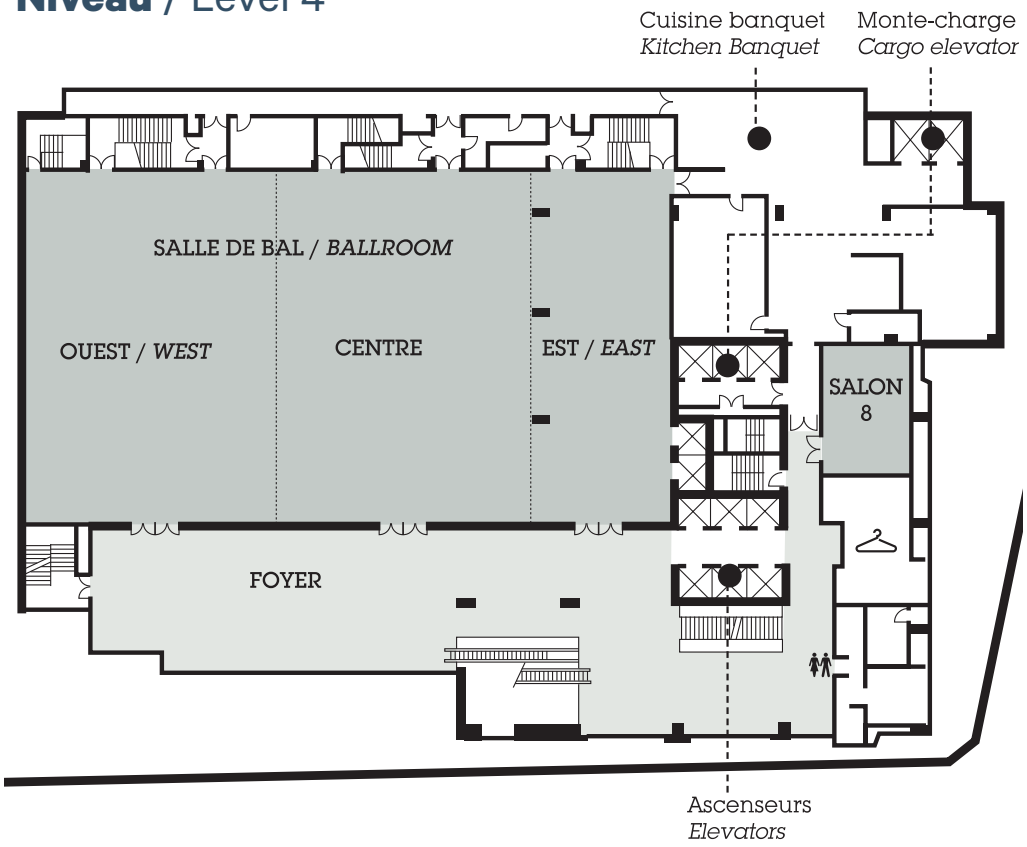
The conference will largely take place on Level 3 and Level 4 of Le Centre Sheraton. Level 3 has the **Drummond** area and Level 4 has the **Ballroom** area. Editorial and society board meetings will take place on Level 2, in the **Salon** area. The registration desk will be in the **Drummond Foyer (Level 3)**.



Niveau / Level 3



Niveau / Level 4



Local information

The hotel provides these suggestions for lunch within walking distance:

- Bistro Le Boulevard, Hotel restaurant located on Lobby Level
- Biermarkt: 1221 René-Lévesque Blvd W, Montreal // lebiermarkt.com
- Escondite Centre Bell: 1224 Drummond St, Montreal, // escondite.ca
- Decca 77, 1077 Drummond St, Montreal // decca77.com
- La Medusa, 1218 Drummond St, Montreal // lamedusa.ca
- Hakata Ramen, 1216 Stanley St, Montreal // hakataramen.ca
- Dunn's Famous, 1249 Metcalfe St, Montreal // dunnsfamous.com

Emergency information

Emergencies

In case of an emergency of any type at the conference hotel, please dial **0** (zero) on any house phone. State your name, location, and the nature of the emergency (e.g., "This is John Doe at Ballroom West. There is a medical emergency."). Hotel security will be notified and dispatched, and emergency services will be alerted if needed. If emergency services are required, all house phones are equipped to place **911** calls directly as well.

Security

To reach the security department at the conference hotel, please dial **0** (zero) on any house phone. The operator will connect you to the security office or agent on duty. Security services are available 24/7 and patrol the hotel.

Alarm and evacuation

The hotel's audible alarms annouce verbal messages in French, then English. If an evacuation is sounded, exit the hotel calmly through the nearest fire exit. The designated assembly point is **1250 René Lévesque**, directly across the street from the hotel.

Code of Conduct

The Society for Mathematical Psychology (SMP) is committed to the highest standards of diversity, equity, inclusion, and the free expression of ideas. We seek to provide an environment in which diverse participants may learn, network, and enjoy the company of colleagues. We recognize a shared responsibility to create and sustain that environment for the benefit of all. This Code of Conduct sets forth our commitment to providing a harassment-free and inclusive environment at SMP sponsored events (including all scientific meetings) as well as for all individuals engaged in SMP related business. **All forms of harassment are prohibited.** Specific prohibited behaviors include but are not limited to the following:

- Harassment or intimidation based on gender, gender identity, gender expression, age, sexual orientation, disability, appearance, body size, race, ethnicity, political orientation and views, religion (or lack thereof), or other group status
- Unwelcome behavior as well as verbal or written comments (including online comments) related to the above categories that create a hostile meeting environment (e.g., sexist or racist jokes)
- Sexual harassment or intimidation, including unwelcome sexual attention
- Unwelcome physical contact
- Harassing photography or recording
- Stalking or following (physical or virtual)
- Sustained disruption or threatening of conference presenters
- Cyberbullying (i.e., the use of computers, cell phones or other devices to send or post emails, text messages or images intended to harass another person) and social media abuse
- Advocating for, or encouraging, any of the above behavior

This code of conduct is not intended to limit the terms of open and respectful scientific inquiry or discussion. Critical examination, debate, and robust disagreement regarding beliefs and viewpoints, germane to the topic of discussion and presented respectfully do not, in themselves, constitute harassment.

We expect individuals to follow this code of conduct at all SMP scientific meetings and in all other SMP related business.

Enforcement

Individuals asked to stop any harassing behavior are expected to comply immediately. If an individual engages in harassing behavior, the SMP executive board retains the right to take any actions to keep SMP a welcoming environment for all individuals. These actions include simply warning the offender, expulsion from a scientific meeting with no refund of registration or other attendance-related costs, expulsion from the society, and/or banishment from all future SMP meetings. Appeals for any of these actions will be handled by the executive board.

Reporting

If you are being harassed, notice that someone else is being harassed, or have any other concerns, please report it to us immediately. We value your involvement in SMP, and will make every effort to ensure that you feel safe and welcome in our society.

You can make a report by emailing `info@mathpsych.org`. This email is directly monitored by the secretary/treasurer and the president. Any reports made by email will be accessible by the executive board. You may also make a report in person to any member of the executive board.

Adopted September 2018

Society for Mathematical Psychology Executive Board

Society President	Jennifer Trueblood
Appointed Members	Robin Thomas, Hans Colonius, Leslie Blaha, Adele Diederich, Scott Brown, and Joachim Vandekerckhove
Elected Members	Clintin Davis-Stober, Chris Donkin, Pernille Hemmer (President-Elect), and Timothy Pleskac

Schedule

Presentation schedule

Friday, July 19, 2019

Time	Salons 6 & 7	Drummond West & Center	Drummond East
09:00 – 10:40	Version control with git (Daniel Stubbs)	The 26^{th} Annual ACT-R Workshop (Christian Lebière)	Dirichlet Process mixture modeling (Yuelin Li)
10:40 – 11:00	*Coffee break (Drummond Foyer)*		
11:00 – 12:40	Version control with git (Daniel Stubbs)	The 26^{th} Annual ACT-R Workshop (Christian Lebière)	Dirichlet Process mixture modeling (Yuelin Li)
12:40 – 14:00	*Lunch break*		
14:00 – 16:00	Effective communication for conflict management (Women of Math Psych)	The 26^{th} Annual ACT-R Workshop (Christian Lebière)	
16:00 – 16:20	*Coffee break (Drummond Foyer)*		
16:20 – 18:00	Effective communication for conflict management (Women of Math Psych)	The 26^{th} Annual ACT-R Workshop (Christian Lebière)	
18:00 – 20:00	*Welcome reception (Drummond Foyer)*		

Saturday, July 20, 2019

Time	Ballroom West	Salons 6 & 7	Drummond West & Center	Drummond East
	Batchelder 1	**Decision making 1**	**Perception and Psychophysics**	**ICCM track**
09:00	Oravecz	Hartmann	Huber	Rosenbloom
09:20	Singmann	Zhou	Bahg	Nobandegani
09:40	Heck	Hotaling	Wirzberger	Chandrasekaran
10:00	Matzke	Davis	Rosendahl	Wang
10:20 – 10:40	*Coffee break (Ballroom Foyer)*			
	Batchelder 2	**Decision making 2**	**Memory 1**	**ICCM track**
10:40	van den Bergh	Pleskac	Shepherdson	Nobandegani
11:00	Schramm	Stober	Westfall	Somers
11:20	Link	Zhao	Caplan	Rosenbloom
11:40	Townsend	Haines	Kahana	West
12:00 – 14:00	*Lunch break*			
14:00 – 15:00	*David Kellen — Early Career Award Lecture (Ballroom West)* *Testing Representations in Recognition Memory: From Model Fits to Critical Tests*			
15:00 – 15:20	*Coffee break (Ballroom Foyer)*			
	Reaction time models	**Process models**	**Memory 2**	**ICCM track**
15:20	Donkin	Akrenius	Kilic	Cranford
15:40	Trueblood	McCarty	Chen	Rahman
16:00	Ludwig	Zhu	Wilson	Riesterer
16:20	Fific	Fox	Schweickert	Seow
17:00 – 20:00	*Poster session (Ballroom Center & East)*			

Sunday, July 21, 2019

Time	Ballroom West	Salons 6 & 7	Drummond West & Center	Drummond East
	Strategy 1	**Accumulator models 1**	**Language**	**ICCM track**
09:00	Gluck	Ngo	Shabahang	Cho
09:20	Gonzalez	Heathcote	Rawski	Rolon-Merette
09:40	Rieskamp	Palestro	Collins	De Jong
10:00	Tenison	Bhatia	Yim	Taatgen
10:20 – 10:40	*Coffee break (Ballroom Foyer)*			
	Strategy 2	**Cognition**	**Vision**	**ICCM track**
10:40	Schulze	Yearsley	Sawada	Briggs
11:00	Heck	Bunji	Glavan	Yang
11:20	Hatz	Perez Santangelo	Liu	Vogelzang
11:40	Lee, M.	Zheng	Broomell	Misra
12:00 – 14:00	*Lunch break*			
14:00 – 15:00	*Maithilee Kunda – ICCM Keynote Address (Ballroom West)* *Imagery-Based AI*			
15:00 – 15:20	*Coffee break (Ballroom Foyer)*			
	Statistical inference	**Neurocognitive modeling**	**Numerical cognition**	**ICCM track**
15:20	van Ravenzwaaij	Cox	Spicer	Hoekstra
15:40	Bamber	Tiganj	Zou	Sibert
16:00	Chechile	Weidemann	Lee, S.-H.	Gluck
16:20	Zhang	Romeu	Grice	Klaproth
16:40 – 17:00	*Coffee break (Ballroom Foyer)*			
17:00 – 18:00	*Business meeting (Ballroom West)*			
18:30 – 22:00	*Conference banquet (Bier Markt)*			

Monday, July 22, 2019

Time	Ballroom West	Salons 6 & 7	Drummond West & Center	Drummond East
	Methods 1	**Symmetry 1**	**Accumulator models 2**	**ICCM track**
09:00	Neufeld	Liu	Diederich	Cranford
09:20	Li	Elder	Wu	Ragni
09:40	Houpt	Sawada	Holmes	Rolon-Merette
10:00	Galdo	Zaidi	Steyvers	Brand
10:20 – 10:40	*Coffee break (Ballroom Foyer)*			
	Methods 2	**Symmetry 2**	**Accumulator models 3**	**ICCM track**
10:40	Schad	Pizlo	Ratcliff	Peebles
11:00	Kennedy	Zhang	Hawkins	Trafton
11:20	Kim		Kvam	Ji
11:40	Gronau		Simen	Sense
12:00 – 14:00	*Lunch break*			
14:00 – 15:00	*Jake Hofman — Society for Mathematical Psychology Keynote Address (Ballroom West)* *How Predictable is the Spread of Information?*			
15:00 – 15:20	*Coffee break (Ballroom Foyer)*			
	Methods 3	**Modeling**	**Decision making 3**	**ICCM track**
15:20	He	Markkula	McCausland	Blaha
15:40	Colonius	Poddiakov	Liew	Wiese
16:00	Cox	Lukeman	Yearsley	Amant

Scheduled events and meetings

Women of Mathematical Psychology network luncheon — July 19, 12:40 – 14:00

the WoMP networking luncheon will take place in **Salons 6 & 7 (Level 3)** of Le Centre Sheraton. This event is only open to conference attendees who have already RSVP'd.

Welcome reception — July 19, from 18:00

An informal welcome reception will be held in the **Drummond Foyer (Level 3)** of Le Centre Sheraton. All conference attendees are invited.

***Journal of Mathematical Psychology* editorial board meeting — July 20, 12:00–14:00**

The annual meeting of the *Journal of Mathematical Psychology* editorial board will take place in **Salon 1 (Level 2)**. This meeting is only open to editorial board members. Lunch will be served.

***Computational Brain & Behavior* editorial board meeting — July 20, 12:00–14:00**

The annual meeting of the *Computational Brain & Behavior* editorial board will take place in **Salon 2 (Level 2)**. This meeting is only open to editorial board members. Lunch will be served.

ICCM board meeting — July 20, 12:00–14:00

The annual meeting of the ICCM board will take place in **Salon 3 (Level 2)**. This meeting is only open to society board members. Lunch will be served.

Poster session — July 20, 17:00–19:00

The poster session will take place in **Ballroom Center & East (Level 4)**. Presenters are asked to mount their posters around 15:00 and to attend their own posters from 17:00. Snacks will be served.

Batchelder memorial — July 20, from 17:00

We will hold an informal get-together to remember our friend and colleague Bill Batchelder. In addition to meeting other friends, colleagues, students, and collaborators of Bill's and to show our respects, this memorial is an opportunity for all to say a few words and share stories from Stanford grad school and other memories of Bill. All are welcome at this meeting in **Ballroom West (Level 4)**.

Society for Mathematical Psychology board meeting — July 21, 12:00–14:00

The annual meeting of the Society for Mathematical Psychology board will take place in **Salon 2 (Level 2)**. This meeting is only open to society board members. Lunch will be served.

Society for Mathematical Psychology business meeting — July 21, 17:00–18:00

The Society for Mathematical Psychology business meeting will take place in **Ballroom West (Level 4)**. At the business meeting, we will announce the *William K. Estes Early Career Award*, the *R. Duncan Luce Journal of Mathematical Psychology Outstanding Paper Award*, the *Newell Best Paper Award*, the inaugural *Computational Brain & Behavior Outstanding Paper Award*, the inaugural *Senior Fellow Award*, the *Best Poster Award*, and the *Journal of Mathematical Psychology Student Travel Awards*. Everyone is welcome at the business meeting.

Conference banquet — July 21, 18:30–22:00

The conference banquet will be held at **Bier Markt**, which is just across Drummond Street from Le Centre Sheraton. A pre-dinner cocktail area is reserved for guests who arrive early. This event is only open to conference attendees who have already RSVP'd. Please bring photo ID.

Plenary presentations

All plenary presentations will be held in **Ballroom West** from 14:00 to 15:00.

Early Career Award lecture by David Kellen (July 20)
Testing Representations in Recognition Memory: From Model Fits to Critical Tests

Author(s): Kellen, David (Syracuse University, United States of America). *Contact:* davekellen@gmail.com.
Abstract: The topic of this talk concerns a long-standing topic in recognition memory, the comparison between discrete, continuous, and "hybrid" modeling accounts of recognition memory. Specifically, I will discuss how this work has traditionally focused on model fits predicated on strong parametric assumptions, and the importance of a shift towards more general, non-parametric approaches. Here, I will show how some classic results in mathematical psychology, such as Falmagne's proof on the Block-Marschak inequalities provide a testable foundation for the general notion that memory judgments are based on a latent-strength representation. I will report empirical results supporting the Block-Marschak inequalities, but also show the close relationship between different types of memory judgments. Finally, I will discuss how these general results can be complemented by critical tests that allow us exclude certain types of representations. The focus will be placed on critical tests that can reject a general class of threshold models.

ICCM keynote lecture by Maithilee Kunda (July 21)
Imagery-Based AI

Author(s): Kunda, Maithilee (Vanderbilt University, United States of America). *Contact:* mkunda@vanderbilt.edu.
Abstract: Despite evidence for the importance of visual mental imagery in many areas of human intelligence, there are few AI systems that use imagery-like knowledge representations to perform complex tasks. My research on imagery-based AI illustrates how imagery-based representations and reasoning operators can be combined to solve standardized tests of nonverbal cognition, like the Raven's Progressive Matrices test; how imagery-based reasoning operators, like mental rotation, can be represented in connectionist systems and learned from perceptual experience; and how interactive technologies that scaffold human mental imagery can be used for applications in special education, data visualization, and more.

Society for Mathematical Psychology keynote lecture by Jake Hofman (July 22)
How Predictable is the Spread of Information?

Author(s): Hofman, Jake (Microsoft Research, United States of America). *Contact:* jmh@microsoft.com.
Abstract: How does information spread in online social networks, and how predictable are online information diffusion events? Despite a great deal of existing research on modeling information diffusion and predicting "success" of content in social systems, these questions have remained largely unanswered for a variety of reasons, ranging from the inability to observe most word-of-mouth communication to difficulties in precisely and consistently formalizing different notions of success. This talk will attempt to shed light on these questions through an empirical analysis of billions of diffusion events under one simple but unified framework. We will show that even though information diffusion patterns exhibit stable regularities in the aggregate, it remains surprisingly difficult to predict the success of any particular individual or single piece of content in an online social network, with our best performing models explaining only half of the empirical variance in outcomes. We conclude by exploring this limit theoretically through a series of simulations that suggest that it is the diffusion process itself, rather than our ability to estimate or model it, that is responsible for this unpredictability.

Friday, July 19, 2019

Morning Tutorial: Version Control with Git (Salons 6 & 7)

Host(s): Stubbs, Daniel (Calcul Québec). *Contact:* daniel.stubbs@calculquebec.ca. *Abstract:* Version control is the lab notebook of the digital world: it's what professionals use to keep track of what they've done and to collaborate with other people. Every large software development project relies on it, and most programmers use it for their small jobs as well. And it isn't just for software: books, papers, small data sets, and anything that changes over time or needs to be shared can and should be stored in a version control system. This is a 3.5h course at a beginner level. Experience with shell commands is useful, but not mandatory. The lesson plan includes these topics: "Automated Version Control", "Setting Up Git", "Creating a Repository", "Tracking Changes", "Exploring History", "Ignoring Things", "Remotes in GitHub", "Collaborating", "Conflicts", and "Open Science, licensing and hosting."

Morning Tutorial: A tutorial on Dirichlet Process mixture modeling (Drummond East)

Host(s): Li, Yuelin (Memorial Sloan Kettering Cancer Center). *Contact:* liy12@mskcc.org. *Abstract:* Bayesian nonparametric (BNP) models are becoming increasingly important in cognitive psychology, both as theoretical models of cognition and as analytic tools. However, existing expositions tend to be at a level of abstraction largely impenetrable by non-technicians. This tutorial aims to explain BNP to the curious non-technicians using the Dirichlet Process (DP) as an illustrative example. DP is one of the most widely used BNP methods. A student researching these topics may encounter terms such as DP and the Chinese Restaurant Process (CRP, one of the construction methods of DP), but he or she may only have a vague impression as to the origin of these somewhat abstract concepts. This tutorial aims to make these concepts more concrete, explicit, and transparent. This tutorial will (1) show what the DP and CRP look like; (2) explain the essential mathematical derivations often omitted in existing expositions you find online; and (3) demonstrate how to write a simple program in the statistical language R to fit a DP mixture model (DPMM). The R program will be explained line by line so that you know precisely how the computation algorithm works. The mathematics will be no more than basic conditional probability and sampling from standard probability distributions. The overall goals are to help you understand more fully the theory and application so that you may apply DP in your own work and leverage the technical details in this tutorial to develop novel methods. By working through the R program and simulated data, you will learn the key feature of DP. The number of clusters is not required to be fixed in advance. The number of clusters used by a DP cognitive theory grows as data accrue and tops when additional clusters no longer explains the data. This tutorial should enhance your appreciation of other tutorials of the DP (e.g., Gershman & Blei, 2012, J. Math Psych; Austerweil, Gershman, Tenenbaum, and Griffiths, 2015, in Busemeyer et al., Oxford Handbook of Computational and Mathematical Psychology). Prerequisite knowledge: Basic familiarity with R (e.g., comfortable with logistic regression in R). Experience with R programming also helps (unfortunately, DP is not yet supported by statistical packages frequently used by behavioral scientists, such as SPSS, Mplus, Stata or SAS). But the programming skills required are no more complicated than writing simple functions. Consider bringing a laptop with R already installed to run the R program right away.

Afternoon Workshop: Effective Communication for Conflict Management (Salons 6 & 7)

Host(s): Women of Math Psych. *Contact:* `WomenOfMathPsych@gmail.com`. *Abstract:* Managing conflict requires readiness to identify and address common fallacies that impede effective communication and productivity. One of the greatest sources of frustration between colleagues is feeling misunderstood. Failure to acknowledge how your words and actions impact others, and vice versa, may weaken your most vital professional relationships. Taking the time and effort to become aware of common logical fallacies may better equip you to quickly resolve negative conflict and avoid unintentional disputes. Here we discuss efficient ways to convey and receive messages in person as well as via phone, email,and social media. Good communication skills will allow you to successfully build relationships and resolve conflict in all stages of your career.

Workshop: The Twenty-Sixth Annual ACT-R Workshop (Drummond West & Center)

Host(s): Christian Lebière

Health and Social Models

9:00am **Peter Pirolli**
ACT-R Models of Health Behavior Change in Mobile Health Change
9:20am **Andrea Stocco**
Computational Psychiatry: Predicting Recovery Curves for PTSD
9:40am **Mark Orr & Parantapa Bhattacharya**
Scaling Social Systems with Cognitive Components

Environments and Applications

11:00am **David M. Schwartz & Christopher L. Dancy**
Building Environments for Simulation and Experimentation in Malmo
11:20am **Nele Russwinkel**
Towards Incorporating Cognitive Models in Applications
11:40am **Robert L. West, Emily Greve, & Elisabeth Reid**
Using Smart Phone Games to Validate ACT-R

Theory and Architecture

2:00pm **Frank E. Ritter, Farnaz Tehranchi, Jacob D. Oury, & Shan Wang**
Testing the KRK Theory Breaks ACT-R and Pilot Data to Show it
2:20pm **Andrea Stocco**
Deriving an Architecture from Brain Data
2:40pm **Niels Taatgen**
Extending ACT-R's Modeling Capabilities: One Level Below, and One Level Above

Future of ACT-R

4:20pm **Dan Bothell**
Software Updates
4:40pm **Everyone**
Open Discussion

Saturday, July 20, 2019, morning

Symposium in Honor of Bill Batchelder (Ballroom West)

Joint modeling of cultural consensus and everyday life experiences

Author(s): Oravecz, Zita[(1)]; Vandekerckhove, Joachim[(2)] (1: Penn State University; 2: University of California, Irvine). *Contact:* zita@psu.edu. *Abstract:* Cultural Consensus Theory (CCT) models allow us to explore shared knowledge or beliefs in a culture. Within this framework, with the Extended Consensus Model (ECM) we can describe individual differences among people in terms of consensus knowledge, willingness to guess, and guessing bias. These cognitive characteristics might have a direct influence on everyday life experiences. To study this, we developed a latent variable model in which process model parameters from intensive longitudinal daily life data and parameters of the ECM can be estimated simultaneously and joined via linear link functions. We apply this model to study whether beliefs on what makes people feel loved are linked to daily life experiences of love.

New Results from the Bayesian and Frequentist MPT Multiverse

Author(s): Singmann, Henrik[(1)]; Heck, Daniel W.[(2)]; Barth, Marius[(3)]; Groß, Julia[(2)]; Kuhlmann, Beatrice G.[(2)] (1: University of Warwick; 2: University of Mannheim; 3: Universität zu Köln). *Contact:* singmann@gmail.com. *Abstract:* Even with a clear hypothesis or cognitive model in mind, most statistical analyses contain several more or less arbitrary choices. In the case of a model-based analysis, these choices can concern the statistical framework, the aggregation-level, and which parameter restrictions to introduce. Usually one path through this 'garden of forking paths' (Gelman & Loken, 2013) is chosen and reported. However, it is unclear how much each choice affects the reported results. The multiverse approach (Steegen, Tuerlinckx, Gelman, & Vanpaemel, 2016) offers a principled alternative in which results for all possible combinations of reasonable modeling choices are reported. We introduce a new software package for R that performs a model-based multiverse analysis for multinomial processing tree (MPT) models, MPTmultiverse. Our package estimates MPT models in a frequentist and Bayesian manner. In the frequentist case, it uses no pooling (with and without bootstrap) and complete pooling. In the Bayesian case, it uses no pooling, complete pooling, and three different variants of partial pooling. Using this MPT multiverse, we performed a meta-analysis for several prominent MPT models (e.g., source-memory, recognition memory). Our results show that even for some core parameters, the different analysis approaches reveal considerable variability in the parameter estimates across estimation methods. Our results suggest that researchers should adopt a multiverse approach when using cognitive models.

Representing Probabilistic Models of Knowledge Space Theory by Multinomial Processing Tree Models

Author(s): Heck, Daniel W.[(1)]; Noventa, Stefano[(2)]; Erdfelder, Edgar[(1)] (1: University of Mannheim; 2: University of Tübingen). *Contact:* heck@uni-mannheim.de. *Abstract:* Knowledge Space Theory (KST) aims at modeling the hierarchical relations between items or skills in a learning process. In KST, the knowledge states of individuals are represented by means of partially ordered latent classes which are mapped to actual response patterns via conditional probability parameters. Since probabilistic KST models account for discrete data by assuming a finite number of latent states, they can be represented by multinomial processing tree (MPT)

models which describe the transitions across latent states by a binary decision tree. This close relationship between MPT and probabilistic KST models has previously been highlighted by Erdfelder (2000) with respect to descriptive and assessment languages (Degreef et al., 1986) as well as stochastic learning processes (Falmagne, 1989, 1990; Falmagne & Doignon, 2011). In contrast to this procedural perspective on assessment, we show that standard probabilistic models of KST such as the Basic Local Independence Model and the Simple Learning Model can be represented as specific instances of MPT models. Given this close link, MPT methods may be applied to address both theoretical and practical questions in KST. For instance, MPT modeling allows to test and account for violations of local independence, a fundamental assumption in Item Response Theory and psychological testing in general.

Bayesian Model Selection and Model Averaging for Multinomial Processing Trees

Author(s): Matzke, Dora[1]; Gronau, Quentin[2]; Heck, Daniel W.[1]; Wagenmakers, Eric-Jan[1] (1: University of Amsterdam, Netherlands, The; 2: University of Mannheim). *Contact:* d.matzke@uva.nl. *Abstract:* Multinomial processing trees (MPTs) are a popular class of stochastic models for the analysis of categorical data. MPT modelers are often faced with the challenge of comparing the descriptive accuracy of a set of MPTs that formalize different theoretical accounts of the data. The candidate models often vary in complexity and are equipped with a large number of parameters, especially when they are implemented in a hierarchical framework. The principled Bayesian solution for such model selection problems is to compute Bayes factors and posterior model probabilities. Both quantities, however, rely on the marginal likelihood, a high-dimensional integral that cannot be evaluated analytically. Here we present Warp-III bridge sampling, a powerful yet straightforward simulation-based approach that enables the accurate computation of the marginal likelihood of complex cognitive models. We illustrate the procedure with published data and demonstrate how Warp-III facilitates Bayesian model averaging for testing parameter constraints in MPTs while fully taking into account model uncertainty.

Cultural Consensus Theory for Psychiatric Assessment

Author(s): van den Bergh, Don; Wagenmakers, Eric-Jan (University of Amsterdam, Netherlands, The). *Contact:* donvdbergh@hotmail.com. *Abstract:* Many psychiatric detention centers monitor patients' mental health at regular intervals. Typically, clinicians score patients using a Likert scale on multiple criteria. Having an overview of patients' scores benefits psychiatric practice in at least three ways. First, the scores may help adjust treatment to the individual patient; second, the change in scores over time allows an assessment of treatment effectiveness; third, the scores may warn staff that particular patients are at high risk of turning violent. Current practices for the analysis of mental health scores are suboptimal: evaluations from different clinicians are averaged (as if the Likert scale were linear and the clinicians identical), and patients are analyzed in isolation (as if they were independent). Uncertainty estimates of the resulting score are often ignored. Here we present a quantitative program for the analysis of mental health scores using cultural consensus theory (CCT; Anders & Batchelder, 2015). CCT models take into account the ordinal nature of the Likert scale, the individual differences among clinicians, and the possible commonalities between patients. In a simulation, we compare the predictive performance of the CCT model to the current practice of aggregating raw observations and, as a more reasonable alternative, against often-used machine learning toolboxes. The presentation is concluded with a discussion on the substantive benefits obtained by application of the CCT model.

Hierarchical Paired Comparison Modeling, A Cultural Consensus Theory Approach

Author(s): Schramm, Pele; Batchelder, William H (University of California, Irvine, United States of America). *Contact:* pschramm@uci.edu. *Abstract:* We introduce a set of models designed to analyze datasets involving

responses from multiple subjects on pairwise comparisons from a fixed discrete set of alternatives.These models are part of a greater body of work known as Cultural Consensus Theory (CCT). Like other CCT models, these simultaneously infer each individual's tendency toward aligning with the group consensus, level of agreement on each item, and also a latent consensus value of each alternative. Two primary models are discussed, referred to as the Strong and Weak Consensus Paired-Comparison Models (SCPCM and WCPCM respectively). The SCPCM works under the assumption that all individuals are answering in accordance to the latent consensus values but with varying degrees of accuracy, while the WCPCM relaxes this assumption and assumes minor deviations from latent consensus values in people's average valuation of alternatives. The WCPCM also includes inferences on participants' individual tendencies toward self-consistency (related to their tendencies toward committing violations of transitivity) as well as inferences on the tendency of each item to be evaluated consistently by individuals. The Case III Thurstonian model is used as the backbone for both CPCMs, and inference is conducted under a hierarchical Bayesian framework. Model checks along with applications to both simulated and real data are overviewed

Axioms versus the Mind

Author(s): Link, Stephen Warren (McMaster University, Canada). *Contact:* `slink@ucsd.edu`. *Abstract:* The axiomatic development of theories was a specialty of Patrick Suppes. Bill Batchelder and the rest of the early Fellows in the Institute for Mathematical Studeies in the Social Sciences were drilled in axiomatics a la Suppes. Axioms must be accepted as reasonable by theoreticians and then used to create testable theoretical predictions that follow from the axioms. In particular the axiom "simple scalability" is satisfied by a set, S, of choice probabilities $P(x, y) = F[(u(x), u(y)]$ where F and u are real-values functions, and $x, y, z, \ldots$ are elements of S. An important aspect of choice situations that may not be met by simple scalability is the effect of context on judgments. Data from a well-known experiment by Tversky and Russo show how context results in failures of simple scalability.

Categorization + Decision Making: Investigation of the Markov Property, Quantal Models and other Good Stuff

Author(s): Townsend, James T.; Liu, Yanjun; Busemeyer, Jerome R. (Indiana University Bloomington, United States of America). *Contact:* `jtownsen@indiana.edu`. *Abstract:* The underlying relationship of cognitive processing is one of essential interests in cognitive science. The basic concept revolves around a two-stage paradigm where observers need to make a categorical decision on a given face (stimulus), and then decide if they would like to be friendly or defensive toward that face. Each stimulus has a certain categorical probability to be assigned to either category A or B, and each category has a certain decisional probability to be friendly or a hostile. Previous research (i.e., Townsend, Silva, Spencer-Smith & Wenger, 2000; Busemeyer & Wang, 2015) discovered an interference effect in this two-stage paradigm that observers' action decision was not independent of visual stimuli, even though the action decisional probability was manipulated to be conditionally independent of visual stimuli. This finding documented a strong violation of the Markov property in the underlying relationship of these two central high-level cognitive processes. This important result has recently been replicated with varing manipulations of the probability structure by Nosofsky & Busemeyer (in preparation). A quantum model (Busemeyer & Wang, 2015) has been developed to capture this interference effect and proved to perform very well (Kvam, Pleskac, Yu & Busemeyer, 2015; Wang & Busemeyer, 2016), assuming a sequential processing order of two stages. Nevertheless, this assumption has not been empirically verified and is being investigated in our current project. This presentation will emphasize the basic phenomenon and touch on the potential quantal and non-quantal hypotheses if time permits.

Decision making 1 (Salons 6 & 7)

Prospect Theory and the Wisdom of the Inner Crowd

Author(s): Hartmann, Stephan (LMU Munich, Germany). *Contact:* s.hartmann@lmu.de. *Abstract:* I present the recently introduced distance-based account of Bayesianism (B. Eva and S. Hartmann, Psychological Review 125(5): 806-821 (2018)) and show how it can be applied to address the problem of probability aggregation. Here we consider a group of experts each of which submits a probability estimate of the occurrence of some event E. We ask: How shall a chairperson aggregate these estimates? According to the distance-based approach, one minimizes the average distance between the aggregate and the individual submissions. I then show that using an f-divergence to measure the "distance" between two probability estimates leads to a number of well-known aggregation functions (such as the normalized geometric mean if one uses the KL divergence) as well as several new aggregation functions which I will examine. The approach can be straight/forwardly generalized to the aggregation of probability distributions. Using these ideas, I then move on and provide a probabilistic justification of the shape of one of the probability weighting functions used in Prospect Theory by drawing on recent work by Herzog and Hertwig (2014) on the wisdom of the inner crowd.

An Introduction to Nonparametric Active Preference Learning

Author(s): Davis, Alex (Carnegie Mellon University, United States of America). *Contact:* alexdavis@cmu.edu. *Abstract:* Learning a decision-maker's preferences requires prior knowledge about the functional form relating preference to choice. Alternatively, modellers may use nonparametric approaches that learn the functional form from data. Active preference learning aims to choose sets of alternatives to maximize the information gained about a decision-maker's preferences. This paper provides an introduction to nonparametric active preference learning models, including additive models, Gaussian Process, and neural networks. Several applications are discussed in the domain of choices between cars, public policies to mitigate climate change, symmetry functions in atomic physics, and part selection for additive manufacturing. The framework is then extended to active structure learning, specifically by using nonparametric preference models to select choice experiments that maximize the chance of transitivity or regularity violations.

Hierarchical Bayesian Models of Choice Decisions in Sequential Risk-Taking Tasks

Author(s): Zhou, Ran; Myung, Jay; Pitt, Mark (The Ohio State University, United States of America). *Contact:* zhou.1500@osu.edu. *Abstract:* In sequential risk-taking tasks such as the Balloon Analogue Risk Task (BART), computational models are used to yield inferences about the underlying cognitive processes, which helps clinical psychologists decompose maladaptive behaviors into distinct cognitive components and understand the cognitive mechanism of these behaviors. Wallsten, Pleskac, and Lejuez (2005) proposed and compared a series of computational models of behavior in the BART, which was later criticized for poor parameter recovery performance of learning parameters and simplified for certain circumstances (van Ravenzwaaij, Dutilh, & Wagenmakers, 2011). Here we take a reinforcement-learning-based approach that involves across-trial adjustment of participant's representation of the balloons' behavior in the BART. Participants in the BART are assumed to learn the optimal strategy to maximize reward by making choices and experiencing the consequences of those choices, which makes it a reinforcement learning problem. We conduct parameter recovery simulations with a Bayesian implementation to assess the performance of the new set of models, and conduct model selection to compare them to the models proposed by Wallsten, Pleskac, and Lejuez (2005). The models are also fitted to empirical data using a hierarchical Bayesian approach as a further test of performance.

New Insights into Decisions from Experience: Using Cognitive Models to Understand How Value Information, Outcome Order, and Salience Drive Risk Taking

Author(s): Hotaling, Jared; Donkin, Chris; Newell, Ben (University of New South Wales). *Contact:* jaredhotaling@gmail.com. *Abstract:* Many real world decisions must be made on basis of experienced outcomes. However, little is known about the mechanism by which people make these decisions from experience. Much of the previous research has focused on contrasting these decisions with those based on described alternatives. Observations of a reliable description-experience gap (D-E gap) led Hotaling, Jarvstad, Donkin, and Newell (under review) to conduct a series of studies investigating various factors influencing decisions from experience. Critically, they found that the juncture at which value and probability information is provided has a fundamental effect on choice. They also found evidence for the impact of perceptual salience and outcome recency on choice. To better understand these results and their implications regarding the mechanisms underlying human decision making, we developed an exemplar-based cognitive model. It uses a noisy error-prone memory mechanism to explain how confusions between events give rise to various behavioral patterns. According to the model, each time an outcome is experienced, a record is laid down in memory. However, memory traces can be disturbed in several ways as new information enters the system. We tested several versions of models within this basic framework, and found that one with mechanisms for value-assignment confusions and risk bias provided the best account. We discuss the implications of these findings on our understanding of the interplay between attention, memory, and choice, and the psychological underpinning of the description-experience gap.

Decision making 2 (Salons 6 & 7)

Would you bet on it? How life's gambles impact people's beliefs

Author(s): Pleskac, Tim[1,2]; Schulze, Christin[2] (1: University of Kansas, United States of America; 2: Max Planck Institute for Human Development). *Contact:* pleskac@ku.edu. *Abstract:* Should and does the mere proposal of a bet alter your beliefs? Decision theory typically treats bets as stimuli by which people reveal their preferences. Yet a bet is also datum that signals the bet-upon event. Based on the hypothesis that bets typically reflect a systematic inverse relationship between risks and rewards, we developed a Bayesian belief-updating model for making inferences from bets. In the model, the player being offered the bet treats the bet as data and, after accounting for biases and uncertainty in the bet itself, uses it to update his or her belief. We tested the predictions of the model with two experiments asking participants to judge the duration and extent of several everyday phenomena. We compared judgments when participants received (a) different amounts of random data samples about the duration of an event, (b) equivalent information communicated via a fair bet, or (c) equivalent information disclosed as a probability estimate. We found that participants integrated the signal carried in the bets they were offered to update their personal beliefs consistent with the Bayesian belief updating model. When participants were offered a bet rather than an explicit probability estimate, they were more uncertain about the conveyed information and tended to believe that bets were more biased than probability forecasts. In sum, our results suggest that people should and do use risk-reward relationships in a social context as a window onto other people's beliefs to construct their own beliefs and preferences.

Testing the Separable Representation of Utility Theories: An Experiment Evaluating Monotonicity, Transitivity, and Double Cancellation

Author(s): Stober, Clintin[1]; Cavagnaro, Daniel[2]; Heck, Daniel[3]; Park, Sanghyuk[1] (1: University of Missouri, Columbia, MO; 2: California State University Fullerton; 3: University of Mannheim). *Contact:* stoberc@missouri.edu. *Abstract:* Additive conjoint measurement (ACM) is a formal theory of measurement

that specifies how two variables relate to a third (Debreu, 1960; Luce & Tukey, 1964). ACM plays a foundational role in many utility-based decision theories, e.g., prospect theory (Kahneman & Tversky, 1979). We report the results of an experiment designed to evaluate the axioms necessary for an ACM representation in a decision making under risk paradigm. These axioms are monotonicity, transitivity, and double cancellation. To test the robustness of the ACM representation, we introduced lotteries involving decisions under ambiguity, where the degree of ambiguity varied across stimulus sets. We applied modern Bayesian order-constrained inference to evaluate the ACM axioms. We tested the collection of axioms jointly for each of the 46 participants. For nearly all participants, we find strong evidence for ambiguity aversion as a function of degree of ambiguity and we find that all three necessary axioms of ACM hold across all experimental conditions.

Bridging the description-experience gap in risky decision-making: Risk sensitive learning as a causal mechanism

Author(s): Haines, Nathaniel; Kvam, Peter D; Turner, Brandon M (The Ohio State University, United States of America). *Contact:* haines.175@osu.edu. *Abstract:* When making decisions based on probabilistic outcomes, people guide their behavior using knowledge gathered through both indirect descriptions and direct experience. However, relying wholly on either described or experienced information often leads to very different decisions. A ubiquitous finding is the so-called description-experience gap, where individuals overweight low probability events when described yet underweight them when experienced. A leading explanation for this fundamental gap in decision-making is that probabilities are weighted differently when learned through description relative to experience, yet a formal theoretical explanation of the mechanism responsible for such differences remains elusive. Here, we demonstrate that changes in probability weighting can be completely explained by risk sensitive learning, which we capture through differential learning of positive versus negative prediction errors. In a simulation study, we show how risk sensitive learning during experience leads to systematically biased estimates of probability weighting when using a traditional CPT model. In a within-subject experiment, we use hierarchical Bayesian modeling and Bayesian model comparison to show that risk sensitive learning captures participants' behavior better than changes in outcome valuation and/or probability weighting across description and experience. We conclude with a discussion of how formal, substantive models of psychological processes can lead to insights that heuristic, statistical models often fail to capture.

Towards a space of contextual effects on choice behavior: Insights from the drift diffusion model

Author(s): Zhao, Wenjia Joyce; Coady, Aoife; Bhatia, Sudeep (University of Pennsylvania, United States of America). *Contact:* zhaowenj@sas.upenn.edu. *Abstract:* Choice behavior can be influenced by many different types of incidental contextual effects, including those pertaining to presentation format, emotion, social belief, and cognitive capacity. Many of these contextual effects form the basis of "nudges", used by academics and practitioners to shape choice. In this paper, we use data from a very large-scale choice experiment to uncover a space of contextual effects. We construct this space by analyzing fifteen contextual effects using the parameters of the drift diffusion model (DDM). DDM is a quantitative theory of decision making whose parameters offer a theoretically compelling characterization of the cognitive underpinnings of choice behavior. By representing a large number of contextual effects in terms of how they influence the parameters of the DDM, our space is able to precisely measure, quantify, and compare the contextual effects, and interpret these effects in terms of their behavioral, mechanistic, and statistical implications.

Perception and Psychophysics (Drummond West & Center)

A unified account of repetition blindness and the attentional blink

Author(s): Huszar, Lucas D. A.[(2)]; Huber, David E.[(1)] (1: University of Massachusetts, Amherst; 2: New York University). *Contact:* lukehuszar@gmail.com. *Abstract:* Chun (1997) examined repetition blindness (RB) in a letter-number attentional blink (AB) task, finding that some manipulations selectively reduced the AB while others selectively reduced the RB. This appears to contradict the 'perceptual wink' model of Rusconi and Huber (2018), which assumes that the AB reflects categorical repetition blindness owing to perceptual habituation. However, perceptual habituation can explain these dissociations considering that in an RSVP paradigm, the RB entails both a deficit for a character's visual appearance and identity (i.e., which letter or number?) as well as a deficit for the target category (i.e., is it a number or a letter?). Providing a unified account of the AB and the RB, we augmented the perceptual wink model with a Bayesian decision process that compares the accumulated evidence in short-term memory against expected priors to determine how many times a particular identity appeared. We assessed this model with three combined AB/RB experiments that manipulated category mapping; for each experiment, one group of subjects received consistent mapping, with a set of characters consistently assigned to the target category, whereas another group received varied mapping, with variation across trials for the target category. The category mapping manipulation affected RB and the AB in a similar manner, as predicted. If both deficits involve a failure to perceive that the second target belonged to the target category, participant should claim that the trial involved only one target. This prediction was confirmed using multiple-choice testing to assess different kinds of errors in the midst of the AB and RB.

A Model-based Explanation of Adaptive Feature-based Learning and Decision

Author(s): Bahg, Giwon; Hsu, Peter; Galdo, Matthew; Kvam, Peter; Turner, Brandon (The Ohio State University, United States of America). *Contact:* bahg.1.osu@gmail.com. *Abstract:* Changes in the environment and feedback about the decision can affect our internal representation of the category distribution (e.g., Turner et al., 2011). More importantly, those external factors can influence the critical aspect of the feature space itself such as whether space is integral or separable (Garner, 1976). In this situation, we need to evaluate which feature dimension is relevant to the decision and need to re-allocate attentional resources dynamically across features to adapt one's decision making criteria through time. However, how adaptivity of human cognition implements attentional dynamics in representational learning and decision has not been explored well. The reason is that this question cannot be studied using traditional categorization models assuming static representations with a specific distributional form. Therefore, in this study, we investigate how changes in the importance of features interact with the development of internal representation and decision processes using Adaptive Representation Model (ARM; Turner, in press). Mainly focusing on behavioral data, we compare different representational (e.g., instance-based vs. strength-based) and learning mechanisms (e.g., similarity kernels, lateral inhibition and error correction) embedded in the ARM to discuss how each mechanism explains adaptive feature-based decision-making and re-allocation of attention. Exploration of neural computation associated with adaptive categorization using a joint modeling approach (Turner et al., 2013) is briefly discussed as a future direction.

A model-based explanation of performance-related changes in abstract stimulus-response learning

Author(s): Wirzberger, Maria[(1)]; Borst, Jelmer P.[(2)]; Krems, Josef F.[(3)]; Rey, Günter Daniel[(4)] (1: Max Planck Institute for Intelligent Systems, Germany; 2: University of Groningen, Netherlands; 3: Cognitive and Engineering Psychology, TU Chemnitz, Germany; 4: Psychology of Learning with Digital Media, TU Chemnitz, Germany). *Contact:* maria.wirzberger@tuebingen.mpg.de. *Abstract:* Stimulus-response learning

constitutes an important part of human experience over the life course. Independent of the domain, it is characterized by changes in performance with increasing task progress. But what cognitive mechanisms are responsible for these changes and how do additional task requirements affect the related dynamics? To inspect that in more detail, we introduce a computational modeling approach that investigates performance-related changes in learning situations with reference to chunk activation patterns. It leverages the cognitive architecture ACT-R to model learner behavior in abstract stimulus-response learning in two conditions of task complexity. Additional situational demands are reflected in embedded secondary tasks that interrupt participants during the learning process. Our models apply an activation equation that also takes into account the association between related nodes of information and the similarity between potential responses. Model comparisons with two human datasets (N = 116 and N = 123 participants) indicate a good fit in terms of both accuracy and reaction times. Based on the existing neurophysiological mapping of ACT-R modules on defined human brain areas, we convolve recorded module activity into simulated BOLD responses to investigate underlying cognitive mechanisms in more detail. The resulting evidence supports the connection of learning effects in both task conditions with activation-related patterns to explain changes in performance.

A Quantum Dynamical Model of Task Landscapes

Author(s): Rosendahl, Lena; Musslick, Sebastian; Cohen, Jonathan (Princeton University, United States of America). *Contact:* mr23@princeton.edu. *Abstract:* One compelling characteristic of controlled processing is our limited ability to exercise it. Theories of control allocation account for such limitations by assuming constraints on how much control can be allocated, leaving open the question of why such constraints would exist. By representing control states as dynamical attractors in a quantum mechanical landscape, we derive a normative explanation for constraints on control allocation. Specifically, we model controlled tasks as square potential wells with width and depth parameterizing task automaticity and control allocated to a task respectively. The agent's cognitive state is represented by the wave and probability density functions of a low mass particle acted upon by the potential wells. We simulate control allocation updating by employing classical control theory heuristics, yielding predictions about control allocation and reward rate dynamics for environments with one or two tasks. Under this model, we can explain and describe, without placing a bound on control allocation, well-understood phenomena such as upper bounds on task performance, the limited ability of control to override automatic processes, as well as cognitive fatigue under a single framework. The model also predicts additional cognitive control phenomena, such as greater variability in reward rate for extremes in control allocation, short term oscillations in attention, and nonlinearity in effort investment as a function of task difficulty. Finally, we discuss how this model can explain a number of other behavioral phenomena, including instructed and voluntary task switching.

Memory 1 (Drummond West & Center)

Continuity with change: How repeated recall affects memory

Author(s): Shepherdson, Peter (University of Akureyri, Iceland). *Contact:* peter@unak.is. *Abstract:* A large body of research attests to the robustness of the testing effect, whereby testing memory for specific information leads to an increased probability of subsequent correct retrieval of that information. In a series of experiments using small sets of visual stimuli I investigated the effect of testing on the content of memory: namely, how participants' recall changes as they are repeatedly tested (without feedback) on their memory for colour. Performance gradually deteriorated with repeated testing, yet responses also became less variable (i.e., memory stabilised). A number of models successfully reproduced the performance deterioration shown in the empirical data, but failed to account for the reduction in variability. Models in which each retrieval produces a novel memory trace, and these traces are noisily sampled from and averaged to form the basis for the

subsequent response, reproduced both key patterns from the data. These findings suggest that part of the benefit of testing may accrue from the creation of new instances in memory with each test, consistent with instance theories of learning and memory.

Changes in semantic memory due to cognitive impairment in Alzheimer's patients

Author(s): Westfall, Holly Anne; Lee, Michael David (University of California, Irvine, United States of America). *Contact:* hwestfal@uci.edu. *Abstract:* In free recall tasks, participants often group their responses by semantic similarity. This response strategy presupposes the existence of an intact similarity-based semantic representation. However, various forms of cognitive impairment could disrupt access to semantic representations. We present an analysis of a clinical dataset of Alzheimer's patients diagnosed with Functional Assessment Stages (FAST), where higher FAST stages represent greater impairment. Participants completed triadic comparisons of animal names and an unexpected delayed free recall task of those animal names. Analyses included a multi-dimensional scaling analysis of semantic representation based on similarity judgments inferred from the triadic comparison data. We also calculated conditional response probabilities (CRP) from the free recall data. As FAST stage increased, semantic representations became less clustered, and CRPs were less related to semantic structure. While it is clear that memory performance changes as cognitive impairment increases, it is not clear whether this change is the result of noisy access to an intact semantic representation or a restructuring of the representation itself. Using the Leuven Concept Database as a source of potential features that patients use to judge the similarity of animals, we develop a model of triadic comparison performance across the FAST stages. The model uses latent-mixture methods to infer which features explain patients' triadic comparison choices, and how consistently they make these choices. The goal of the analysis is to understand the relative importance of changes in access to a stable representation versus changes in the semantic representation itself, as patients' semantic memory becomes progressively more impaired.

Item-memory emerges from association memory when you forget to mean-center

Author(s): Caplan, Jeremy B.; Xu, Kaiyuan; Jones, Kelvin E.; Chakravarty, Sucheta (University of Alberta, Canada). *Contact:* jcaplan@ualberta.ca. *Abstract:* Anderson (1970) introduced two models that are at the core of artificial neural network models as well as cognitive mathematical models of memory. The first, a simple summation of items, represented as vectors, can support rudimentary item-recognition. The second, a heteroassociative model consisting of a summation of outer products between paired item vectors, can support cued recall of associations. Anderson recommended fixing the mean element value to zero, for simplicity, and with minimal loss of generality. However, in a realistic neural network model, if element values are represented by firing rates, as is commonly done, this mean-centering is violated, because firing rates cannot be negative. We show, analytically, that adding a bias to item representations produces interference from other studied list items, makes the model worse at cued recall, but tempts the model to make intrusion responses not unlike human participants. However, an unexpected feature appears: when probed with a constant vector, containing no "information," the model retrieves a weighted sum of studied items, formally equivalent to Anderson's item-memory model. This echoes of Hockley and Cristi's (1996) findings that associative study strategies led to high item-recognition, but not vice versa. We show that such a model can achieve high levels of performance (d'), when the bias is greater than zero, but not too large relative to the standard deviation of element values. Thus, when modellers have striven for realism and relaxed mean-centering, such models may not only still function at adequate levels, but acquire a spin-off functionality that can actually be used, without the need for additional encoding terms specific to item-memory.

Modality effects in free recall: A retrieved-context account

Author(s): Kahana, Michael J.; Pazdera, Jesse K. (University of Pennsylvania, United States of America). *Contact:* kahana@psych.upenn.edu. *Abstract:* The modality effect refers to the robust finding that memory performance differs for items presented aurally, as compared with visually. Whereas auditory presentation leads to stronger recency performance in immediate recall, visual presentation often produces better primacy performance. To investigate these differences, we conducted two large-scale immediate free recall experiments via Amazon Mechanical Turk. In both experiments, participants studied visual and auditory word lists of varying lengths and rates of presentation. We observed a recency advantage and primacy disadvantage during auditory trials, relative to visual trials, reflecting common modality and inverse modality effects in free recall. Participants were more likely to initiate recall from recency items on auditory trials than on visual trials, though the modality effect persisted regardless of recall start location. Meanwhile, an analysis of intrusion errors revealed that participants were more likely to erroneously recall words from one list prior on visual trials than they were on auditory trials. We discuss our findings within the framework of retrieved-context theories of episodic memory, fitting the Context Maintenance and Retrieval model to our data in order to develop a retrieved-context account of the modality effect. Through our simulations, we demonstrate that both the modality and inverse modality effects can be explained as products of faster context drift and stronger context-to-item association formation during auditory presentation, relative to visual. Finally, we demonstrate that our model predicts the persistence of the modality effect across recall start positions, as well as the novel effects of modality we observed on prior-list intrusion behavior.

ICCM track 1 (Drummond East)

An Architectural Integration of Temporal Motivation Theory for Decision Making *Author(s):* Paul S. Rosenbloom and Volkan Ustun

Decoy Effect and Violation of Betweenness in Risky Decision Making: A Resource-Rational Mechanistic Account *Author(s):* Ardavan S. Nobandegani, Kevin da Silva Castanheira, Thomas R. Shultz and Ross Otto

Memory of relative magnitude judgments informs absolute identification *Author(s):* Adithya Narayan Chandrasekaran, Narayanan Srinivasan and Nisheeth Srivastava

The model that knew too much: The interaction between strategy and memory as a source of voting error *Author(s):* Xianni Wang, John Lindstedt and Michael Byrne

ICCM track 2 (Drummond East)

On Robustness: An Undervalued Dimension of Human Rationality *Author(s):* Ardavan S. Nobandegani, Kevin da Silva Castanheira, Timothy J. O'Donnell and Thomas Shultz

Cognitive-Level Salience for Explainable Artificial Intelligence *Author(s):* Sterling Somers, Constantinos Mitsopoulos, Robert Thomson and Christian Lebiere

(A)symmetry x (Non)monotonicity: Towards a Deeper Understanding of Key Cognitive Di/Trichotomies and the Common Model of Cognition *Author(s):* Paul S. Rosenbloom

Put Feeling into Cognitive Models: A Computational Theory of Feeling *Author(s):* Robert West and Brendan Conway-Smith

Saturday, July 20, 2019, afternoon

Reaction time models (Ballroom West)

Bringing nudges into the lab: Using evidence accumulation models to understand the role of external influences on decision-making

Author(s): Donkin, Chris; Newell, Ben (UNSW Sydney, Australia). *Contact:* c.donkin@unsw.edu.au. *Abstract:* The standard approach to understanding the role of external influences on decision making, or nudges, has been top-down. Research has focused on finding low-cost interventions that change behaviour in real-life scenarios. Our aim with this project is to take a bottom-up perspective. We use the well-studied area of simple decision making and accompanying theoretical models, such as the diffusion model (Ratcliff, 1978), as the lens through which to study external influences on behaviour. We present the first step in this project, an experiment in which participants were asked to judge a stimulus as bright or dark. Before some decisions, participants were told about the behaviour of their peers (e.g., "70% of the other participants responded dark to the upcoming stimulus"). We also varied the difficulty of the task, from impossible to relatively easy. We found that participants responded more in line with the norm information when the task was impossible, but that behaviour was unaffected by norm information when the task was easier. Interestingly, when we analysed the data with a diffusion model, we found that difficulty had no effect on the parameters of the model. The norm information affected the start-point of evidence accumulation, with the norm information being a single of evidence for the appropriate response before the trial began. However, the norm information had practically no influence on the rate at which evidence accumulated, with decisions being driven only by the properties of the stimulus under evaluation. Together, this suggests that the interaction between the efficacy of the social norm information and uncertainty/difficulty emerged out of the architecture of the decision-making apparatus, but did not exist at the latent, psychological level.

Prevalence induced Biases in Medical Image Decision-making

Author(s): Trueblood, Jennifer[(1)]; Holmes, William[(1)]; O'Daniels, Payton[(1)]; Eichbaum, Quentin[(2)]; Seegmiller, Adam[(2)]; Stratton, Charles[(2)] (1: Vanderbilt University, United States of America; 2: Vanderbilt University Medical Center, United States of America). *Contact:* jennifer.s.trueblood@vanderbilt.edu. *Abstract:* Despite significant technical improvements in cancer imaging and training of specialists, diagnostic errors still occur with rates estimated to be 10% or greater. Importantly, diagnostic decisions based on medical images are often influenced by the prevalence of abnormalities, arising from either[(1)] naturally high or low rates of disease in clinical samples or[(2)] censoring / prioritization of images for review by automated systems. Through the application of a joint deep convolutional neural network (CNN) and diffusion decision model (DDM), we quantify the latent cognitive processes that are influenced by prevalence in both experts and novices. Using a diagnostic decision task involving the classification of digital images of blood cells as either normal (Non-Blast) or cancerous (Blast), we find that prevalence leads to a response bias (a change in the start-point in the CNN-DDM) for novices and both a response bias and stimulus bias (a change in the drift rate in the CNN-DDM) for experts. The presence of a response bias in both experts and novices is consistent with prior work in perceptual decision-making where the proportion of stimuli is varied (White & Poldrack, 2014). The presence of a stimulus bias in experts indicates that the evaluation of a case is dependent on information from other, independent cases. This suggests that there is a relative component to information processing in experts' diagnostic decisions.

Temporal control in modelling eye fixations

Author(s): Ludwig, Casimir[1]; Trukenbrod, Hans[2]; Engbert, Ralf[2] (1: University of Bristol, United Kingdom; 2: University of Potsdam, Germany). *Contact:* c.ludwig@bristol.ac.uk. *Abstract:* In natural vision, processing difficulty will change periodically during sequences of fixations. To ensure adaptive behaviour, it is important that fxation duration is adjusted to systematic changes in difficulty. We aim to understand these temporal control mechanisms by developing and fitting computational models to extended sequences of fixations. Observers generated large sequences of fixations in a gaze-contingent paradigm where the fixated item cued the direction of the next saccade. Items were embedded in visual noise, which changed periodically to increase or decrease processing difficulty. The key features of our data are: fixation duration adapts immediately to an increase in processing difficulty; adaptation to increasing difficulty initially “overshoots”, but then decreases again to a new steady state; adaptation of fixation duration to decreasing difficulty tends to be delayed (but not always). Here we report simulations and Bayesian fits of a model based on evidence accumulation to a threshold. The model has three key mechanisms that operate on different timescales: (i) during the first fixation after any change in difficulty, foveal inhibition transiently reduces the drift rate; (ii) the drift rate itself varies with the quality of evidence presented during a given fixation; (iii) the decision threshold adjusts over the course of several fixation in response to the recently experienced processing difficulty. These mechanisms themselves are symmetric with respect to processing difficulty. However, their interaction over different timescales explains the asymmetry in adaptation between increasing and decreasing difficulty, as well as the initial overshoot in fixation duration after an increase in difficulty.

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

Author(s): Fific, Mario[1]; Yang, Cheng-Ta[2]; R. Little, Daniel[3] (1: Grand Valley State University; 2: National Cheng Kung University; 3: The University of Melbourne). *Contact:* fificm@gvsu.edu. *Abstract:* The other-race effect refers to the difficulty of discriminating between faces from ethnic and racial groups other than one’s own. Researchers mostly agree that a major culprit behind the other-race effect is the inability to utilize a fast holistic face perception. It is hypothesized that perception of other race faces uses a slow analytic perception of facial features. In the cross-cultural study we compared both Asian (Taiwanese) and Caucasian (US) participants’ face discrimination of both own-race and other-race faces (Taiwanese and Caucasian woman), according to their nose-to-mouth separation and eye-to-eye separation. However, one of the possible confounding factors in understanding the other-race effect could be possible true racial differences in facial features, such as the feature discriminability rate. To control for the facial feature discrimination rate across racial groups we adjusted individual participants’ facial feature discriminability using psychophysical methods and created face sets so that the facial perceptual effects are constant, for both the own- and other-race faces. Then we employed factorial design using the psychophysically adjusted configural facial features in a face categorization task. We applied a parametric system factorial technology (SFT) analysis of the response times and choice preferences for the full factorial stimulus set. The results of the computational modelling challenged the traditional approach to the other-race effect. Almost all of the subjects used parallel processing of the facial features while some subjects, of both races, utilized facilitatory parallel processing showing the across-feature dependency (parallel facilitatory model) which supports a strong form of holistic hypothesis.

Process models (Salons 6 & 7)

Information Theory Meets Expected Utility: The Entropic Roots of Probability Weighting Functions

Author(s): Akrenius, Mikaela (Indiana University Bloomington, United States of America). *Contact:* makreniu@indiana.edu. *Abstract:* In this talk, I propose that the shape and parameter fits of existing

probability weighting functions can be explained with sensitivity to uncertainty (as measured by information entropy) and the utility carried by reductions in uncertainty. Building on applications of information theoretic principles to models of perceptual and inferential processes, I suggest that probabilities are evaluated relative to the distribution of maximum entropy (the uniform distribution) and that the perceived distance between a probability and uniformity is influenced by the shape (relative entropy) of the distribution that the probability is embedded in. These intuitions are formalized in a novel probability weighting function, VWD(p), which is simpler and has less free parameters than existing probability weighting functions. VWD(p) captures characteristic features of existing probability weighting functions, introduces novel predictions, and provides a parsimonious account of findings in probability and frequency estimation related tasks.

Applying Dynamic Cognitive Models of Intertemporal Choice to Addiction

Author(s): McCarty, Kayleigh N.; Hatz, Laura E.; Segert, Simon; McCarthy, Denis M.; Davis-Stober, Clintin P. (University of Missouri, United States of America). *Contact:* knmmv4@mail.missouri.edu. *Abstract:* Within the field of drug and alcohol addiction, delay discounting is typically modeled using classical hyperbolic discounting models. Recent work suggests that such models incompletely represent the nature of intertemporal choice. We argue that dynamic Bayesian cognitive models are more appropriate because they jointly account for the choice behavior and the cognitive processes contributing to the choice. We administered a standard delay discounting task to a sample of social drinkers (n = 47) as part of an alcohol administration study. We fit static and dynamic models to the intertemporal choice data. Results indicated that the dynamic model fit the intertemporal choice data well. We will discuss the implications of using dynamic models of intertemporal choice in general and as applied to addiction. We will highlight the advantages of dynamic models over traditional modeling approaches. Finally, we will discuss how dynamic models of intertemporal choice might improve our understanding of addiction and how problematic patterns of decision making develop over time.

The Bayesian Sampler: Generic Bayesian Inference Causes Incoherence in Human Probability Judgments

Author(s): Zhu, Jianqiao[(1)]; Sanborn, Adam[(1)]; Chater, Nick[(2)] (1: University of Warwick, United Kingdom; 2: Warwick Business School, United Kingdom). *Contact:* j.zhu@warwick.ac.uk. *Abstract:* Human probability judgments are systematically biased, in apparent tension with Bayesian models of cognition. But perhaps the brain does not represent probabilities explicitly, but approximates probabilistic calculations through a process of sampling, as used in computational probabilistic models in statistics. Naïve probability estimates can be obtained by calculating the relative frequency of an event within a sample, but these estimates tend to be extreme when the sample size is small. We propose instead that people use a generic prior to improve the accuracy of their probability estimates based on samples, and we call this model the Bayesian sampler. The Bayesian sampler trades off the coherence of probabilistic judgments for improved accuracy, and provides a single framework for explaining phenomena associated with diverse biases and heuristics such as conservatism and the conjunction fallacy. The approach turns out to provide arational reinterpretation of "noise" in an important recent models of probability judgment, the probability theory plus noise model (Costello & Watts, 2014, 2016, 2017,2019; Costello, Watts, & Fisher, 2018), making equivalent average predictions for simple events, conjunctions, and disjunctions. The Bayesian sampler does, however, make distinct predictions for conditional probabilities, and we show in a new experiment that this model better captures these judgments both qualitatively and quantitatively.

A Bayesian Model of Multi-tasking Efficiency across Time

Author(s): Fox, Elizabeth L[1,2]; Houpt, Joseph W[2] (1: Air Force Research Labs, WPAFB OH; 2: Wright State University, Dayton OH). *Contact:* fox.119@wright.edu. *Abstract:* In applied settings, it may be valuable to estimate multi-tasking performance and use the information online, i.e., near real-time. The primary concern of online measures is the their relative intrusiveness. Detrimental outcomes may occur if the measure requires an interruption or augmentation that interferes with the primary task(s). Our Bayesian model of multi-tasking throughput (MT) is passive, unobtrusive, and offers the temporal precision to estimate efficiency over small bins of time with relatively few observations (i.e., response times, samples of tracking error). Generally, we found fluctuation in MT that varied across four multi-task conditions, at the individual-level. The range of variation in our data demonstrates the value for us to further develop our relatively simple Bayesian model to obtain smooth, fine-grained estimates of MT across time. Users may benefit from timely feedback; they can rapidly test and evaluate numerous strategies to accommodate the demands of multiple tasks. Additionally, online estimates of MT may inform time sensitive task augmentation and offer a way to more efficiently deploy adaptive automation or human enhancement.

Memory 2 (Drummond West & Center)

Retrieval dynamics of output interference: Testing decreases accuracy and slows item recognition

Author(s): Kilic, Asli (Middle East Technical University, Turkey). *Contact:* askilic@metu.edu.tr. *Abstract:* Output interference (OI) is one form of forgetting due to a decline in accuracy as the number of tested items increases. This decline in accuracy could stem from encoding of test trials, changing context over the course of testing or metacognitive processes such as a decrement in vigilance towards the end of testing. Such a decrement in vigilance can be observed as a decline in accuracy with speeded responses towards the end of the test list. In order to test whether OI can still be observed when speed-accuracy tradeoff is controlled over the course of testing, a response deadline version of a 2AFC recognition task was employed. To further investigate the role of drifting context in OI, both study-test lag and retention intervals were controlled. In addition to controlling processing time, this procedure allowed independent estimates of OI's effects on retrieval success and dynamics. Results indicate that retrieval success decreased and retrieval slowed towards the end of the test list. These findings indicate that OI is still observed even in the absence of speed-accuracy tradeoff, which is inconsistent with the sole vigilance hypothesis. On the other hand, decreased accuracy along with slowed retrieval supports the interference caused by encoding of test items in recognition memory.

The Source of List Strength Effect in Recall

Author(s): Chen, Sharon; Criss, Amy (Syracuse University, United States of America). *Contact:* ychen117@syr.edu. *Abstract:* List strength effect (LSE) constrains memory models, and hence is of importance to study. The list strength paradigm asks whether strong memories affect other memories in the same list. Consistently, we have found strong memories harm other memories in free recall (a positive LSE), don't affect other memories in cued recall (a null LSE), and benefit other memories in recognition (a negative LSE). Reliance on context or item information in the retrieval cue has been thought to be the source of LSE (Ratcliff, Clark and Shiffrin, 1990; Shiffrin, Ratcliff, & Clark, 1990). However, in a typical experimental design, cue type is confounded with the level of competition. A context cue is shared by all items and memories compete to get sampled, therefore the competition is high. An item cue is uniquely paired with another item and the competing memory set is narrow, producing a low level of competition. Therefore, in this project, we manipulated both cue type and the level of competition independently in a list strength paradigm. Data shows the direction and magnitude of LSE was determined by whether the cue is shared by all, half of, a quarter of

the items, or one unique item. There was no effect of whether the cue is context or item. We discussed our results within the framework of the retrieving effectively from memory (REM) model.

Evidence for global matching during memory recovery

Author(s): Wilson, Jack H.; Criss, Amy H. (Syracuse University, United States of America). *Contact:* jhwilson99@gmail.com. *Abstract:* The act of recall includes sampling and recovery processes. Sampling is the selection of a memory trace to recall. Recovery is the act of transforming the sampled memory trace into a response. The Search of Associative Memory (SAM) model's account of recovery states that the probability of recovery depends on the local strength of the target item. In this model, recovery probability should not be influenced by the memory of other studied items. We test this model assumption by allowing the to-be-retrieved target word in a paired associates cued recall test to either be related or unrelated to another untested word on the study list. This similarity manipulation is counterbalanced with the similarity of the cue word, which also either does or does not have a related word on the study list. Critically, the presence of a related target in the study list improves both correct response and intrusion rates, while the presence of a related cue increases intrusions, but not correct response rates. The presence of similar items on the study lists facilitates recovery in some fashion, suggesting the role of a global match process during recovery.

Frequencies of Characters Occurring in Dreams

Author(s): Schweickert, Richard; Zheng, Xiaofang (Purdue University, United States of America). *Contact:* schweick@purdue.edu. *Abstract:* People occur in dreams with different frequencies. The probability distribution of frequencies was examined in dream reports of five dreamers, obtained from DreamBank.net. Characters in each dream were coded. For each dreamer, frequencies followed a power law distribution. A Poisson distribution was also considered, but fit poorly. An explanation in broad terms is given by the Continuity Hypothesis of Hall and Nordby, "there is a close correspondence between what a person dreams about and what he does and thinks when he is awake." According to this hypothesis, because frequencies of contact with people often follow a power law in daily life, frequencies of characters in dreams do so also. A more detailed explanation is given by analogy with the people naming task. In one model of this task, the subject takes a random walk on his or her semantic memory network for people and their relations. A well-known theorem implies that if a network is connected and has a power law degree distribution, then the frequencies with which vertices are visited in a random walk follows a power law. We illustrate this with a simulation. We also simulate a random walk on a network with a power law degree distribution, but which is disconnected. The frequencies with which people are visited do not follow a power law. However, the frequencies follow a variant with an additional parameter, the Zipf-Mandelbrot Law. Frequencies of characters in dreams can be explained by a random walk on the dreamer's semantic memory for people.

ICCM track 3 (Drummond East)

Modeling Cognitive Dynamics in End-User Response to Phishing Emails *Author(s):* Edward A. Cranford, Christian Lebiere, Prashanth Rajivan, Palvi Aggarwal and Cleotilde Gonzalez

SpotLight on Dynamics of Individual Learning *Author(s):* Roussel Rahman and Wayne Gray

Predictive Modeling of Individual Human Cognition: Upper Bounds and a New Perspective on Performance *Author(s):* Nicolas Riesterer, Daniel Brand and Marco Ragni

Transfer effects from varied practice and adaptation to changes in complex skill acquisition *Author(s):* Roderick Yang Terng Seow, Shawn Betts and John Anderson

Sunday, July 21, 2019, morning

Symposium on Recent Developments in Modeling Strategy Use in Searching and Deciding (Ballroom West)

Measures and Models of Strategy Switching in Decision Processes

Author(s): Gluck, Kevin[1]; Lee, Michael[2] (1: Air Force Research Laboratory, United States of America; 2: University of California - Irvine). *Contact:* kevin.a.gluck@gmail.com. *Abstract:* Emerging technologies embolden our visions for a future in which the machines in our lives are more like partners, teammates, and coaches, rather than merely tools. We want our future software and robotic assistants to provide personalized, adaptive, and proactive support in achieving our goals. Progress toward these visions requires improving their ability to make accurate inferences about our cognitive processes on the basis of relatively sparse data. They need to understand not just what we are doing, but also how we are doing it, if they are to provide guidance and help us achieve better outcomes more efficiently. Here we describe efforts to bring various measurement and modeling methods together for higher resolution inferences about peoples' decision-making processes. A key focus of these efforts has been the investigation of how stable decision strategies are. In other words, what evidence is there for strategy switching when we investigate decision-making variability on a trial-by-trial basis? We bring together combinations of process and outcome measures with hierarchical Bayesian models of decision strategies and switch point detection, then extend those mechanisms and evaluate the method across previously published datasets from the decision making literature.

Emergence of Collective Cooperation and Network Connections from Self Interests

Author(s): Gonzalez, Cleotilde; Korosh, Mahmoodi (Carnegie Mellon University, United States of America). *Contact:* coty@cmu.edu. *Abstract:* Emergence of collective cooperation in an inherently selfish society is a paradox that has preoccupied biologists, sociologists, and cognitive scientists alike for centuries. We propose a computational model and demonstrate through simulations how collective cooperation can emerge from selfish interests: the goal of improving each individual's own rewards. We also demonstrate how the same selfish interests leads of the dynamic emergence of networks of interconnected agents. Our model includes two simple mechanisms we call Selfish-Trust (ST) and Selfish-Connection (SC). ST involves the possibility of relying on others in a society of agents when it is beneficial to the individual, and SC involves the possibility of connecting to other agents when those agents help improve the individual's own benefit. Our simulation results suggest that collective cooperation can emerge from ST and that a network can emerge from ST. The simulated data demonstrates an important property of many living organisms: patterns of temporal complexity which are essential to transfer information among agents of any society of living beings.

The effect of time pressure on decision making under risk: Strategy selection can explain increases of errors

Author(s): Rieskamp, Joerg; Olschewski, Sebastian (University of Basel, Switzerland). *Contact:* joerg.rieskamp@unibas.ch. *Abstract:* Recent studies claimed that time pressure can change risk preferences in decision making under risk. However, these inferences are often based on group choice proportions. When choice proportions deviate from 50% in control, a significant change towards 50% could either be modeled as a change in preferences or as an increase in error. Without a stochastic choice model,

one cannot distinguish between both hypotheses. In two studies (n=40 and n=60), we examined risky choices with and without time pressure in a within-subjects design. In each condition, people chose 120 times between two gambles that varied in expected value and variance. Using Bayesian hierarchical estimation of utility functions with a probit choice function, we showed that time pressure decreased consistency that is leading to more errors but did not systematically affect risk preferences. To explain the increase of error we follow a strategy selection hypothesis according to which people select compensatory strategies under low time pressure and non-compensatory strategies under high time pressure. Consistent with this hypothesis the error increase under high time pressure could be partly explained by a switch to simpler, non-compensatory decision strategies under high time pressure.

Curating Educational Content: Unsupervised Modeling of Users Behavior on Pinterest

Author(s): Tenison, Caitlin; MacLellan, Christopher; English, Brittney; Cowell, Tyree; Sheline, Rob (Soar Technology, United States of America). *Contact:* caitlin.tenison@soartech.com. *Abstract:* Digital curation sites, such as Pinterest, act as platforms for the collection, organization and sharing of web content. Curation is a categorization activity in which an individual gathers and organizes items into collections, creating an artifact that has value beyond the sum of each item. Within the field of education, Pinterest has become a professional tool for identifying content, methods, and ideas that teachers can use within the classroom (Carpenter, Abrams, and Dunphy, 2016). In interviews, educators describe using Pinterest for several different purposes (e.g. lesson preparation, browsing, sharing). Further, they identify a wide variety of content they collect in these activities (e.g. subject specific content, classroom management, professional development) (Hu, Torphy, Opperman, Jansen and Lo, 2018). In the current study, we use unsupervised machine learning to model pinning strategies of teachers and educational bloggers engaged in digital curation on Pinterest. First, we apply a variety of clustering techniques to establish what information is being communicated by a given pin. Next, we use hidden Markov modeling to infer how users move between pins of different types, both within and across their Pinterest sessions. These models enable us to infer user's intents and strategies. Prior work exploring Pinterest use models of content and behavior separately, using post-hoc analyses to show evidence for the relationship between the two (Bandari, Xiang, Leskovec, 2017). In our research, we combine content information with Pinterest user activities to infer their curation behaviors and strategies.

Who You Know is What You Know: Modeling Individual and Developmental Differences in Boundedly Rational Social Sampling

Author(s): Schulze, Christin; Hertwig, Ralph; Pachur, Thorsten (Max Planck Institute for Human Development, Germany). *Contact:* cschulze@mpib-berlin.mpg.de. *Abstract:* A person's social environment provides an informative sampling space for making inferences about key characteristics of the world at large–such as the distribution of preferences or risks. How do people search this sampling space and how do they make decisions based on the sampled instances? Inspired by models of bounded rationality in multiple-cue inference and in accord with research on the structure of social memory, we develop and test the social-circle model, a parameterized, probabilistic process account of how people judge the relative frequency of events. The model extends the prominent notion that cognitive search is structured and limited to decisions based on social sampling and it permits to capture individual differences in the order in which sampling spaces are inspected, in aspiration levels, and in response error. Using a hierarchical Bayesian latent-mixture approach, we submit the model to a rigorous model comparison. In Study 1, a reanalysis of previously published data, we find that the social-circle model outperforms both a model assuming exhaustive search and a simple heuristic that assumes no individual differences in search and evidence accumulation. Study 2 establishes the robustness of these findings in a different judgment domain and with individuals from different age groups (adults and children). Our results indicate that already children rely on limited and structured social sampling when making

inferences and illustrate how individual differences in boundedly rational social sampling can be conceptualized and measured.

Testing informative hypotheses about latent classes of strategy users based on probabilistic classifications

Author(s): Heck, Daniel W.[(1)]; Davis-Stober, Clintin P.[(2)]; Cavagnaro, Daniel R.[(3)] (1: University of Mannheim; 2: University of Missouri; 3: California State University, Fullerton). *Contact:* heck@uni-mannheim.de. *Abstract:* Strategy selection aims at classifying participants as users of different decision strategies. By operationalizing each strategy as a statistical model on choice probabilities and response times, model-selection techniques such as the Bayes factor allow researchers to test competing strategies. For each participant, this method provides posterior model probabilities defined as the probabilities that each of the competing strategies generated the observed pattern of responses. Recently, the theoretical and statistical sophistication of model-selection methods and models has steadily increased. However, to draw conclusions on the group level (e.g., "does a majority of participants use a specific strategy?"), researchers often classify each person as a "user" of the strategy with the highest posterior probability. Whereas being simple, this deterministic approach ignores the classification uncertainty of any model-selection method. As a remedy, we extend a recent model-based test for probabilistic classification by Cavagnaro and Davis-Stober (2019) to estimate the relative group sizes of strategy users while accounting for classification uncertainty and to test informative hypotheses about these latent classes (e.g., "most participants used strategy X or Y"). The method requires only posterior model probabilities (or information-theoretic weights) per person as input and can easily be applied using the R package "multinomineq" for multinomial models with inequality constraints. We reanalyze the data by Heck, Hilbig, and Moshagen (2017) and present Monte Carlo simulations to assess the effect of ignoring classification uncertainty when drawing inferences on the group level.

Associations Between Sexual Decision Making, Behavior, and Expectancies Using Order Constrained Bayesian Inference

Author(s): Hatz, Laura E.; McCarty, Kayleigh N.; Park, Sanghyuk; McCarthy, Denis M.; Davis-Stober, Clintin P. (University of Missouri, United States of America). *Contact:* leh352@mail.missouri.edu. *Abstract:* In a previous study, we administered a novel sexual gambles task, adapted from economic gambles stimuli, in which participants made repeated choices between hypothetical sexual partners based on physical attractiveness and risk of contracting a sexually transmitted infection (STI). Bayesian model selection revealed that the vast majority (98%) of participants utilized a compensatory strategy (i.e., a numerical utility representation) when choosing amongst hypothetical sexual partners in the task. Follow-up analyses using a p-median clustering algorithm (Brown et al., 2016) revealed a large amount of between-subject variability in choice behavior within this classification. In the present study, we expand on these findings by testing associations between cluster membership and self-reported sexual behavior and expectancies for sexual risk taking. Two independent samples of young adults (N = 192, N = 65) completed the sexual gambles task and a self-report measure assessing frequency of past sexual behavior, expected positive consequences of sexual behavior, and expected negative consequences of sexual behavior (CARE-R; Katz, et al., 2000). Participants reported on expectancies for sexual activity with both regular and new sexual partners. We used order constrained Bayesian inference to test associations between these indices of sexual behavior and attitudes and choice behavior on the sexual gambles task. We will present results of these analyses and discuss their implications.

A sequential sampling framework for understanding strategies in cue-based multi-alternative choice

Author(s): Lee, Michael; Gluck, Kevin (University of Califorina Irvine). *Contact:* mdlee@uci.edu. *Abstract:* Many cognitive strategies have been proposed as accounts of how people choose between alternatives that are represented by a set of cues. Long established strategies include the take-the-best (TTB), tally, and weighted additive (WADD) strategies. More recently, these strategies have been extended in various ways, including probabilistic versions of TTB and WADD, and parameterized extensions of TTB to the k-Reason strategy and tally to the tally-k strategy. We show that all of these strategies can be considered as special cases of sequential sampling models, using both random-walk and accumulator evidence accrual processes. Using sequential sampling as a unifying framework allows basic theoretical questions raised by the use of strategies to be examined. Is search terminated by a criterion involving the extent of search or the level of evidence found? Does evidence take the form of cue counts or continuous measures dependent on cue validities? Are decisions deterministic once bounds are reached or do they remain sensitive to the number of cues searched or levels of evidence reached? Is evidence for competing alternatives commensurable, as for random walks, or non-commensurable, as for accumulators? We begin to address these questions using Bayesian methods to apply sequential sampling models to a corpus of previously-collected data measuring people's behavior in cue-based multi-alternative choice.

Accumulator models 1 (Salons 6 & 7)

The effect of stimulus presentation time on bias: A diffusion-model based analysis

Author(s): Ngo, Jeremy; Donkin, Chris (University of New South Wales). *Contact:* jeremy.ngo@unsw.edu.au. *Abstract:* There are two main types of bias in simple decision tasks, response bias and stimulus bias. Response bias is a reduction in the evidence required for one response, and stimulus bias is the evaluation of stimuli in favor of a biased response. Differences in the relative frequency of presented stimuli are typically thought to induce response bias, though previous research has sometimes reported an effect on stimulus bias. We use a two-alternative forced-choice brightness discrimination task in which we manipulate the presentation length of the stimuli. We analyze the resultant data with a hierarchical diffusion model. The results show an overall response bias, but also find that stimulus bias increases as stimulus presentation time decreases. We argue that the results challenge the typical stationarity assumption of the diffusion model, but rather suggest that participants may be accumulating evidence based on factors other than the stimulus throughout the course of the trial. Follow up studies were run to try to further examine if manipulating stimulus ambiguity can approximate the same pattern of results observed in manipulations of stimulus presentation time. The results hint at a relationship between stimulus ambiguity and stimulus bias and a process model is discussed.

A multiple threshold race model of response time, confidence and accuracy.

Author(s): Reynolds, Angus[(1)]; Heathcote, Andrew[(2)] (1: University of Tasmania, Australia; 2: University of Tasmania, Australia). *Contact:* angus.reynolds@utas.edu.au. *Abstract:* The Multiple Threshold Race (MTR) model uses Vicker's (1979) idea that confidence is linked to the amount of evidence accumulated by the looser in an evidence-accumulation race. It adds multiple thresholds, with a response triggered when the winner crosses the highest threshold and confidence determined by multiple lower thresholds (e.g., a low-confidence response occur if the looser's evidence at is above the second highest threshold). We instantiated this idea using the LBA (Brown & Heathcote, 2008) and show it gives an accurate account of confidence data modeled by Starns and Ratcliff (2008), with the exception of a few participants showing an atypical pattern of faster low than high confidence responses. These exceptions were accommodated by allowing low-confidence responses to sometimes be triggered by crossing a low threshold. We then show this model fails to fit fast high

confidence errors in Ratcliff et al.s (1994) data but that this can be accommodated by an MTR base on Heathcote and Love's (2012) LNR model when positive correlations are allowed between accumulation rates. Both LBA and LNR variants of the MTR have analytic likelihoods and are measurement models (i.e., data generating parameters can be recovered through fits to realistic samples), although for the correlated LNR this only true with confidence ratings. We discuss how MTR models can be used to synthesize the joint information available in response time and benchmark accuracy and metacognition relative to optimal performance.

Decisions and Dynamic Evidence

Author(s): Palestro, James[(1)]; Kvam, Peter[(1)]; Molloy, M. Fiona[(1)]; Keyser, Corey[(1)]; Tsetsos, Konstantinos[(2)]; Turner, Brandon[(1)] (1: The Ohio State University, United States of America; 2: University Medical Center Hamburg-Eppendorf, Germany). *Contact:* jpalestro@gmail.com. *Abstract:* Traditional models of perceptual decision making assume that noisy sensory evidence is integrated across time for each choice alternative until a threshold amount of evidence has been reached. Despite decades of successful applications, most support for these models come from tasks that feature discrete trials with stationary perceptual evidence and a predictable evidence onset time, making it difficult to directly investigate the integration process that informs a subject's decision over time. Here, we explore the integration process more closely by attempting to characterize data from a continuous random dot motion task, where subjects are presented with a cloud of randomly moving dots whose motion strength (i.e., the proportion of dots moving in one direction) updates every second according to a hidden Markov model. By comparing the projected accumulation paths of various mathematical models to the observed behavior, we gain insight into the moment-to-moment dynamics of evidence integration, allowing for a more complete understanding of decision formation.

Context in Decisions from Memory

Author(s): Zhao, Wenjia Joyce; Richie, Russell; Bhatia, Sudeep (University of Pennsylvania, United States of America). *Contact:* zhaowenj@sas.upenn.edu. *Abstract:* We present a framework for studying naturalistic memory-based choice. Our framework implements leading cognitive theories of semantic representation, memory search, and decision making, within a single integrated computational model. With reasonable assumptions about how context interacts with memory and preference, this model can be jointly fit on recall and choice data. The parameter values obtained from such fits shed light on how people represent information in decisions tasks, how they sample this information in memory, and how sampled information is aggregated over time to form a decision. We showcase the power and generality of our framework by applying it to naturalistic memory-based decisions in consumer, financial, health, social, and policy-related domains.

Cognition (Salons 6 & 7)

Is there a classical explanation for interference effects of choice on confidence?

Author(s): Yearsley, James Mathew[(1)]; Evans, Nathan[(2)]; Trueblood, Jennifer[(3)] (1: City, University of London, United Kingdom; 2: University of Amsterdam; 3: Vanderbilt University). *Contact:* james.yearsley@city.ac.uk. *Abstract:* Recent research within decision-making has generated interest in "quantum" models of cognition: models that use the mathematics of quantum theory to account for violations of classical causal inference observed in empirical data. One commonly observed violation, termed the "interference effect", occurs when averaging over the outcomes of a judgment produces results different from not eliciting the judgment at all. In a recent paper Kvam et al. (2015) reported an "interference" effect of an initial decision in a random dot motion task on a subsequent confidence judgment, and interpreted this as

providing support for a quantum model of decision making. We question this conclusion by constructing a classical model based on the Linear Ballistic Accumulator model, and showing it is able to account for the reported effect. Further we show the empirical effect is more subtle than first appreciated, and there are aspects not captured by the quantum model of Kvam et al. (2015), but that are explained by our classical model.

Cognitive process model for ordered categorical response and response time data for questionnaires

Author(s): Bunji, Kyosuke[(1,2)]; Okada, Kensuke[(1)] (1: The University of Tokyo, Japan; 2: Japan Society for the Promotion of Science). *Contact:* bunji@p.u-tokyo.ac.jp. *Abstract:* The diffusion item response theory model (DIRT) successfully combines the benefits of psychometric and cognitive modeling approaches. DIRT can be used to jointly model item response and response time information. However, because DIRT is based on the diffusion model, it is only applicable to dichotomous response data. Conversely, polytomous scales that have more than two ordered categories, such as five-point Likert scales, are typically used in psychology to measure personality traits. Compared to these scales, the amount of information per item that is obtained from dichotomous responses is substantially limited. Therefore, the main objective of this study is to propose a cognitive process model that is applicable to any data with an ordered categorical response format. For this purpose, we extend the linear ballistic accumulator (LBA) IRT model (LIRT) instead of DIRT. The LBA framework allows us to represent the data generating mechanism of response time for polytomous items. The proposed model incorporates the relationship wherein the closer the trait level of the respondent is to the item location on a latent psychological continuum, the longer it takes to respond to the item. In a simulation study, we show that the proposed model can properly estimate the parameters under many conditions, such as different numbers of points in a scale and different numbers of items. Furthermore, we applied the proposed model to real personality data with an ordered categorical response format. We also discussed the advantages of the proposed model compared to existing DIRT and LIRT models.

The beatable mind: cognitive effects of music tempo on human decision-making, a model-based approach.

Author(s): Perez Santangelo, Agustin; Navajas, Joaquin; Sigman, Mariano; Leone, Maria Juliana (Laboratorio de Neurociencia - Universidad Torcuato Di Tella). *Contact:* asantangelo@utdt.edu. *Abstract:* Decision-making is essential to life. Decisions are often summarized by response times and accuracy. However, drift-diffusion models (DDMs) have gained popularity since they accurately describe and predict human decision behavior. These models break down decisions into psychologically-relevant parameters that describe process dynamics which map onto the activity of region-specific neurons. Although studies have shed light on how contextual stimuli impact on decision-making, few have shown which aspects are sensitive to them and how. To address this question, we centered on the effects of real-life stimuli concurrent with the decision-making process. Specifically, we were interested in stimuli capable of inducing an urgency signal. We focused on music speed (tempo), and proposed that faster tempo would induce faster decisions, which would be reflected on changes in DDM parameters: a higher evidence-accumulation rate and/or a lower decision threshold. To test this hypothesis, we designed an extensive decision-making task battery that included decisions about perceptual -motion coherence and numerosity- stimuli, general knowledge, lexicality, preferences and morality. As predicted, faster tempo generally induced faster responses at the expense of accuracy, and this was mainly captured by changes in evidence threshold. However, an interaction with task type was found, revealing a more intricate relationship between the effects of tempo and complexity on decision-making. These findings suggest that music tempo modulates decision-making in a non-homogenous and cross-domain fashion. Furthermore, these results impact directly in our real-life experiences: a common and ubiquitous stimulus is able to shape our decisions.

Integrating Categorization and Decision

Author(s): Zheng, Rong; Busemeyer, Jerome; Nosofsky, Robert (Indiana University Bloomington, United States of America). *Contact:* zhengro@iu.edu. *Abstract:* We investigated how people integrate category information with decision-making in two categorization-decision experiments. Participants were shown faces, and asked to categorize the faces, and also asked to decide a course of action for each face. Each experiment included three groups, and for each group we manipulated the probabilistic contingencies between stimulus, category feedback and decision feedback. In order to investigate interference between categorization and decision-making processes, each group received four different sequences of category response, category feedback, decision response, and decision feedback. Empirical tests provided strong evidence for the group effects produced by probabilistic contingencies, and condition effects produced by response sequences. We also compared the performance of a quantum cognition model versus a traditional exemplar model to quantitatively account for the observed results. The basic empirical results as well as the quantitative model comparisons and evaluations will be presented in this paper.

Language (Drummond West & Center)

An Associative Theory of Semantic Composition

Author(s): Shabahang, Kevin; Dennis, Simon; Yim, Hyuwngwook (University of Melbourne, Australia). *Contact:* k.shabahang@gmail.com. *Abstract:* We present a new version of the Syntagmatic-Paradigmatic model (SP; Dennis, 2005) as a representational substrate for encoding meaning from textual input. We depart from the earlier SP model in three ways. Instead of two multi-trace memory stores, we adopt an auto-associative network. Instead of treating a sentence as the unit of representation, we go down a scale to the level of words. Finally, we specify all stages of processing within a single architecture. We show how the model is capable of forming representations of words that are independent of the surface-form through some question-answering examples. We end with a discussion of how the current model can provide a point-of-contact between static and dynamic accounts of semantic composition.

Geometric Representations of Linguistic Structures and Computations

Author(s): Rawski, Jonathan; De Santo, Aniello; Graf, Thomas; Heinz, Jeffrey (Stony Brook University, United States of America). *Contact:* jonathan.rawski@stonybrook.edu. *Abstract:* Computational claims about language distill the necessary and sufficient conditions of its underlying mental processes. Recent mathematical linguistic results point to a restriction in both memory requirements and in data structures across a wide variety of linguistic phenomena, formalized using subclasses of the regular languages (Thomas, 1997; Heinz, 2018). These characterizations are supported by typological studies and artificial grammar learning experiments (Finley, 2011; Lai, 2015; Avcu et al., 2018). Here we discuss the properties of linguistic structures themselves. There is a deep connection between specific representational choices and the nature of the linguistic processes. For example, many liguistic phenomena rely on seemingly long-distance non-local relationships (e.g., vowel harmony, subject/verb agreement), but over the right representation such processes turn out to be local. We use Finite Model Theory to show that over different representations (strings and trees) supposed computational distinctions between phonological and syntactic processes disappear (Rogers & Pullum, 2011; Heinz & Idsardi, 2013; Graf, 2014). This points to a unified view of memory requirements across linguistic processes, providing a theoretical basis for experiments testing where the nature of human biases in language and learning comes from. Additionally, model-theoretic characterizations provide a clear link to geometrical interpretations of linguistic processes via multilinear algebra. Structures like strings and trees can be translated into tensor product representations (Smolensky 1990). We expand these characterizations to

consider model-theoretic structures of any type, providing a flexible link between formal language theory and dynamical systems approaches to linguistic cognition (Gerth & beim Graben, 2012; beim Graben, 2008).

Predictive Validity of a Cognitive Model in a Naturalistic Language Learning Task

Author(s): Collins, Michael[(1)]; Jastrzembski, Tiffany[(1)]; Krusmark, Michael[(2)]; Sense, Florian[(3)]; van Rijn, Hedderik[(3)]; Harris, Jack[(4)]; Gaines, Alex[(1)]; Haubert, Ashley[(5)]; Martinez, Siera[(6)] (1: Air Force Research Laboratory, United States of America; 2: L-3 Communications at the Air Force Research Laboratory; 3: University of Groningen; 4: Infinite Tactics; 5: University of Dayton Research Institute; 6: Ball Aerospace). *Contact:* trustproject123@gmail.com. *Abstract:* Learning management systems, such as Duolingo, allow people access to personalized second language education. These systems track individuals' performance across multiple skills and present problems that are expected to maximize learning. Guiding learning management systems are skills acquisition models (e.g., Bayesian knowledge tracing and neural networks) that consider an individuals' frequency, recency, previous accuracy and other task features to predict future performance. Predicted performance can then be used to determine personalized learning schedules. However, many skill acquisition models do not consider the temporal distribution of learning events (i.e., spacing effect), which is necessary to account for learning over educationally relevant periods of time (i.e., weeks, months, years). One cognitive model of learning and retention that incorporates the spacing effect over these time frames is the Predictive Performance Equation (PPE). The PPE has high predictive validity across distinct sets of laboratory and applied tasks (Walsh, et al., 2018). Here we examine PPE's ability to predict human performance in a naturalistic setting: people learning a second language on the Duolingo learning platform. We evaluate PPE's predictive validity across multiple levels of aggregation and different time scales, and evaluate PPE to published metrics from competing non-cognitive models (Table 2 in Settles, et al., 2018). We demonstrate that PPE accounts for human learning and forgetting using only performance accuracy and temporal schedule as inputs. This research holds promise for developing a method for personalized optimized training in a range of educational and training domains.

Semantic integration of novel words through syntagmatic and paradigmatic associations

Author(s): Yim, Hyungwook[(1)]; Savic, Olivera[(2)]; Unger, Layla[(2)]; Sloutsky, Vladimir[(2)]; Dennis, Simon[(3)] (1: The University of Melbourne & University of Tasmania, Australia; 2: The Ohio State University; 3: The University of Melbourne). *Contact:* hyungwook.yim@gmail.com. *Abstract:* We present a novel demonstration of how new words can be integrated into existing lexico-semantic networks based on syntagmatic (i.e., associations among words that co-occur in a context) and paradigmatic associations (i.e., associations among words that are interchangeable in a context). In the experiment, participants read sentences where familiar and novel words either directly co-occurred in a sentence or shared patterns of co-occurrence with another word. We observed that, immediately after reading the sentences, new words came to prime familiar words with which they co-occurred (syntagmatically related) or shared co-occurrence in sentences (paradigmatically related). The finding represents a novel demonstration that new words can be integrated into lexico-semantic networks from exposure to distributional regularities. By extending the model structure that was proposed by Sloutsky, Yim, Yao, & Dennis (2017), we provide a model that accounts for the experimental results.

Vision (Drummond West & Center)

The Geometry and Perception of 3D Mirror- and Rotational-Symmetry

Author(s): Sawada, Tadamasa; Farshchi, Maddex (Higher School of Economics, Russian Federation). *Contact:* tada.masa.sawada@gmail.com. *Abstract:* 3D mirror-symmetry is the critical a priori constraint that the human visual system uses to perceive a 3D shape veridically. This makes the detection of the 3D mirror-symmetry of a shape very important for the perception of an object's 3D shape. It is well known that the human visual system is very sensitive to the 3D mirror-symmetry of a given shape. This sensitivity can be attributed entirely to geometrical properties of the 3D mirror-symmetry. Now note that the properties of 3D rotational-symmetry are geometrically analogous to, but more complex than the properties possessed by 3D mirror-symmetry. This made it reasonable to postulate that our visual system might be less sensitive to 3D rotational-symmetry. We studied this possibility by directly comparing a human observer's perception of 3D mirror-symmetry with the same observer's perception of 3D rotational-symmetry. We used the signal detection method to measure the discrimination of 3D symmetric and 3D asymmetric pairs of contours and found that only 3D mirror-symmetry discrimination was reliable. Our results suggest that the human visual system processes these two types of symmetry very differently.

Parallel processing of color and shape during visual search

Author(s): Glavan, Joseph; Houpt, Joseph (Wright State University, United States of America). *Contact:* glavan.3@wright.edu. *Abstract:* The mechanisms guiding visual attention are of great interest to cognitive and perceptual psychologists. Many researchers have proposed models of these mechanisms, which serve to both formalize their theories and to guide further empirical investigations. The assumption that a number of basic features are processed in parallel early in the attentional process is common among most models of visual attention and visual search. To date, much of the evidence for parallel processing has been limited to set-size manipulations. Unfortunately, set-size manipulations have been shown to be insufficient evidence for parallel processing. In a series of studies, we applied Systems Factorial Technology, a general nonparametric framework, to test this assumption, specifically whether color and shape are processed in parallel or in serial. In previous experiments we examined search for a known target when either a single feature distinguished a target from distractors (feature search), or when two features together distinguished a target (conjunctive search). In the current study, we extend these findings to odd-one-out search for an unknown target. Together with our previous experiments, we have strong evidence that color and shape information guides visual search in parallel. We found facilitatory processing when the target is known, but unlimited capacity independent processing in odd-one-out search. These results confirm core assumptions about color and shape feature processing instantiated in most models of visual search and provide more detail about the manner in which color and shape information is combined to guide search.

An Investigation of the Characteristic Properties of Cognitive Processes with Perceptually Integral Stimuli

Author(s): Liu, Yanjun[(1)]; Zhang, Ru[(2)]; Townsend, James T.[(1)]; Wenger, Michael J.[(3)] (1: Indiana University Bloomington, United States of America; 2: University of Colorado Boulder; 3: University of Oklahoma). *Contact:* yanjun1130@gmail.com. *Abstract:* General recognition theory (GRT, Ashby & Townsend, 1986) is a nonparametric generalization of signal detection theory that characterizes possible dependencies in perceptual representation in terms of the presence or absence of violations of perceptual independence (PI), perceptual separability (PS) and decisional separability (DS), using response-frequency-based measures obtained in a complete identification (CID) paradigm. Systems factorial technology (SFT, Townsend & Nozawa, 1995) is a nonparametric theory that characterizes the fundamental properties of information processing (architecture,

stopping rule, capacity, and independence) using reaction-time (RT) obtained in a double factorial classification paradigm (DFP). The present study applied both GRT and SFT using a set of rectangular stimuli whose width and height were varied; these stimuli have previously been shown to be perceived in a perceptually integral manner (Macmillan & Ornstein, 1998). In addition, we manipulated response bias by running both tasks first using payoff matrixes designed to encourage unbiased respond and second using payoffs biased toward specific stimuli, testing the hypothesis that the combined use of GRT and SFT would allow for converging sources of evidence regarding inferred perceptual representations and processing characteristics. Results suggest observers (N = 8) violated PS in both the unbiased and biased conditions, and that parallel exhaustive processing was implicated for all observers in the unbiased condition and for three of four observers in the biased condition. The violation in PS indicated by GRT and the parallel exhaustive processing indicated by SFT document strong evidence to support previous findings of perceptually integral processing of rectangular stimuli and provided converging inferences by both theories, including consideration of individual differences. This coherent characterization of perceptual integral manner by both theories suggests a strong potential in the combination of GRT and SFT, allowing a more complete picture of information processing to be developed, including principled accounts of individual differences.

Global-Local Incompatibility: The Misperception of Reliability in Judgment Regarding Global Variables

Author(s): Broomell, Stephen (Carnegie Mellon University, United States of America). *Contact:* broomell@cmu.edu. *Abstract:* I present a new analytic model of judgment regarding global variables. This model provides a unified framework for studying judgment that has implications for several important real world domains, including hiring decisions, global warming, and weather hazards. Such variables demand public attention, cannot be directly observed by a single decision maker (DM), and require the integration of observations from locally available information cues. This model predicts a unique form of overconfidence in judgment caused by generalizing the predictability of the local environment to a global scale. I show that the local perspective is often less reliable for predicting global variables than expected, creating global-local incompatibility. While local perspectives vary across DMs, global-local incompatibility can be understood using the structure of classical test theory to model (a) perceptions of the reliability of the local environment and (b) the true reliability of the local environment. Reliability is an unobservable coefficient defining the consistency of observations and the upper bound of their validity. When two cues are assumed to equal the global variable in expectation and to be statistically independent, they are defined as parallel, and their correlation estimates reliability. I therefore model perceived reliability as the observed correlation between locally observable cues, which are assumed by the DM to be parallel. I outline three contexts where psychological research reveals salient cues with hidden violations of this assumption, demonstrating the ubiquity of global-local incompatibility. I conclude by discussing how this model expands cognitive-ecological theory, predicts miscalibrated judgment, and provides insights for improving calibration.

ICCM track 4 (Drummond East)

Simulating Problem Difficulty in Arithmetic Cognition Through Dynamic Connectionist Models *Author(s):* Sungjae Cho, Jaeseo Lim, Chris Hickey, Jung Ae Park and Byoung-Tak Zhang

Learning and Recalling Arbitrary Lists of Overlapping Exemplars in a Recurrent Artificial Neural Network *Author(s):* Damiem Rolon-Merette, Thadd Rolon-Merette and Sylvain Chartier

Flexible Timing with Delay Networks fftti The Scalar Property and Neural Scaling *Author(s):* Joost de Jong, Aaron Voelker, Hedderik van Rijn, Terrence Stewart and Chris Eliasmith

A Spiking Neural Architecture that Learns Tasks *Author(s):* Niels Taatgen

ICCM track 5 (Drummond East)

A cognitively plausible algorithm for causal inference *Author(s):* Gordon Briggs and Sangeet Khemlani

Syntactic Priming Depends on Procedural, Reward-Based Computations: Evidence from Experimental Data and a Computational Model *Author(s):* Yuxue Yang and Andrea Stocco

The Role of Discourse in Italian Pronoun Interpretation: Investigating Variations in Experimental Results with Cognitive Modeling *Author(s):* Margreet Vogelzang

Measuring the Influence of L1 on Learner English Errors in Content Words within Word Embedding Models *Author(s):* Kanishka Misra, Hemanth Devarapalli and Julia Rayz

Sunday, July 21, 2019, afternoon

Statistical inference (Ballroom West)

Quantifying Evidence for the Absence of an Effect: A Comparison of Three Methods for Testing Equivalence

Author(s): van Ravenzwaaij, Don[(1)]; Selker, Ravi[(3)]; Linde, Maximilian[(1)]; Wagenmakers, Eric-Jan[(2)] (1: University of Groningen, Netherlands, The; 2: University of Amsterdam, Netherlands, The; 3: NA). *Contact:* d.van.ravenzwaaij@rug.nl. *Abstract:* When employing hypothesis testing, it can be of interest to quantify evidence in favor of the absence of an effect as well as for the presence of an effect. Because traditional p-value hypothesis tests do not allow researchers to quantify evidence in favor of the absence of an effect (or in favor of the equivalence between conditions), several alternative methods have been proposed. In this talk, we compare three such methods in terms of statistical power: the frequentist two one-sided t-tests (TOST) method, the Bayesian region of practical equivalence (ROPE) method, and the JZS Bayes factor for non-overlapping interval hypotheses (JZS-BF). Crucially, all three methods use the same band of equivalence. The differences and similarities between the methods are assessed using simple analytical derivations and a simulation study. Our results demonstrate that JZS-BF require only relatively small sample sizes to discover true equivalence, whereas TOST and ROPE require sample sizes that are often unrealistic to have an acceptable chance of discovering true equivalence.

Should Updated Bayesian Models be Tested for Goodness of Fit?

Author(s): Bamber, Donald (University of California, Irvine, United States of America). *Contact:* dbamber@uci.edu. *Abstract:* We consider the question: After a Bayesian model has been updated by conditioning on data, should it be tested for goodness of fit to data? We consider this question from the standpoint of three different interpretations of Bayesian models.

- Epistemic interpretation: The rational way to update a model is by conditioning on data. Once this has been done, it is irrational to further modify the model. Thus, there is no reason to evaluate the model's goodness of fit to data.
- Pragmatic interpretation: A model's goodness of fit to data should be evaluated after updating. But why this is so, has not been adequately explained.
- Mimetic interpretation: After updating, a model's goodness of fit should be evaluated because the updated model may mimic Nature incredibly poorly. (An example of this is given.)

A Novel Bayesian Analysis for the Kendall Tau Correlation

Author(s): Chechile, Richard (Tufts University, United States of America). *Contact:* richard.chechile@tufts.edu. *Abstract:* In this paper a Bayesian analysis is developed for a population proportion (phi) that is directed related to the Kendall tau correlation, i.e., the population tau is equal to (2 phi)-1. There is an exact solution for any set of n bivariate observations for the coefficients that characterize the

prior and posterior distribution for the phi parameter. This analysis can be especially useful in assessing scientific theories. Several examples will be described in detail.

Information Geometry: A Mathematical Foundation of Statistical Inference, Learning and Information

Author(s): Zhang, Jun (University of Michigan, United States of America). *Contact:* junz@umich.edu. *Abstract:* Information Geometry is the differential geometric study of the manifold of probability models, and promises to be a unifying geometric framework for investigating statistical inference, information theory, machine learning, etc. Starting from "divergence functions" for measuring proximity of two points on the manifold (that do not impose symmetry and triangular inequality, in metric geometry), for instance Kullback-Leibler divergence, Bregman divergence, f-divergence, etc.., the framework captures the principle of "reference-representation biduality" in which the reference-point effect and representational transformation are tightly coupled. Divergence functions are tied to generalized entropy (for instance, Tsallis entropy, Renyi entropy, phi-entropy) and cross-entropy functions widely used in machine learning and information sciences. It turns out that divergence functions enjoy pleasant geometric properties - they induce what is called "statistical structure" on a manifold M: a Riemannian metric g together with a pair of affine connections D, D* coupled in special way. This talk will introduce to the math psych community to the powerful tools of information geometry by demonstrating how non-informative priors in Bayesian inference are handled in such framework.

Neurocognitive modeling (Salons 6 & 7)

A dynamic model of target selection in visual search by neurons in frontal eye fields

Author(s): Cox, Gregory Edward[(1)]; Palmeri, Thomas J.[(1)]; Schall, Jeffrey D.[(1)]; Logan, Gordon D.[(1)]; Smith, Philip L.[(2)] (1: Vanderbilt University, United States of America; 2: The University of Melbourne, Australia). *Contact:* gregcox7@gmail.com. *Abstract:* Eye movement behavior in visual search can be predicted by treating saccade decisions as the outcome of a process that accumulates evidence from a representation of salience maintained in the frontal eye fields (FEF; Purcell, Schall, Logan, & Palmeri, 2012). This representation evolves dynamically, with FEF neurons initially responding to the presence of any item in their receptive field, but later evolving to differentiate between targets (higher firing rate) and distractors (lower firing rate). Because saccades depend on accumulating this dynamic evidence signal, understanding how this signal changes with manipulations like set size helps explain why those manipulations affect search speed and accuracy. We present a model of these neural dynamics based on the competitive interaction theory of Smith and Sewell (2013) which instantiates three key ideas: 1) FEF neuron firing rates reflect the degree of attention allocated to their corresponding part of the visual field; 2) attention is differentially allocated as a function of competitive interactions between FEF cells; 3) target selection is the result of a positive feedback loop as attention enables detection of target features which in turn attract more attention. The model describes how visual attention evolves from being attracted exogenously by display onset to being concentrated endogenously on the target, connecting neural processing dynamics with normalization mechanisms invoked in cognitive theories of attention (e.g., Bundesen, 1990); the model reproduces the neural dynamics used to predict behavioral effects of set size by Purcell et al. (2012), strengthening the link between neural activity and behavior.

A neural architecture for cognitive models

Author(s): Tiganj, Zoran; Cruzado, Nathanael; Howard, Marc W. (Boston University, United States of America). *Contact:* zoran.tiganj@gmail.com. *Abstract:* Constrained by results from classic behavioral experiments we

provide a neural-level cognitive architecture for navigating memory and decision making space. We propose a canonical microcircuit that can be used as a building block for working memory, decision making and cognitive control. The controller controls gates to route the flow of information between the working memory and the evidence accumulator and sets parameters of the circuits. We show that this type of cognitive architecture can account for results in behavioral experiments such as judgment of recency, item recognition and delayed-match-to-sample. In addition, the neural dynamics generated by the cognitive architecture provides a good match with neurophysiological data from rodents, monkeys and humans. For instance, it generates cells tuned to a particular amount of elapsed time (time cells), to a particular position in space (place cells) and to a particular amount of accumulated evidence.

Neural Activity Reveals Interactions Between Episodic and Semantic Memory Systems During Retrieval

Author(s): Weidemann, Christoph Thomas[1,2]; Kahana, Michael Jacob[2] (1: Swansea University, United Kingdom; 2: University of Pennsylvania). *Contact:* ctw@cogsci.info. *Abstract:* Whereas numerous findings support a distinction between episodic and semantic memory, it is now widely acknowledged that these two forms of memory interact during both encoding and retrieval. The precise nature of this interaction, however, remains poorly understood. To examine the role of semantic organization during episodic encoding and retrieval, we recorded intracranial encephalographic signals as 69 neurosurgical patients studied and subsequently recalled categorized and unrelated word lists. Applying multivariate classifiers to neural recordings, we were able to reliably predict encoding success, retrieval success, and temporal and categorical clustering during recall. By assessing how these classifiers generalized across list types, we identified specific retrieval processes that predicted recall of categorized lists and distinguished between recall transitions within and between category clusters. These results particularly implicate retrieval (rather than encoding) processes in the categorical organization of episodic memories.

A Bayesian joint model of two similar but separable neurocognitive tasks

Author(s): Kvam, Peter D[1]; Romeu, Ricardo J[2]; Turner, Brandon M[3]; Busemeyer, Jerome R[2]; Vassileva, Jasmin[4] (1: University of Florida, United States of America; 2: Indiana University Bloomington, United States of America; 3: The Ohio State University, United States of America; 4: Institute for Drug and Alcohol Studies, Virginia Commonwealth University, United States of America). *Contact:* kvam.peter@gmail.com. *Abstract:* Cognitive modeling of neurocognitive tasks is a powerful technique that allows one to analyze the cognitive components of a phenomenon more thoroughly. More powerful still is the ability to connect multiple cognitive models from different tasks measuring the same phenomenon, with consistent models converging onto a robust picture of the construct. We present an application of the joint modeling approach (Turner et al., 2013), one method of connection, to better understand impulsivity as measured by two popular neurocognitive tasks: the Kirby Delay Discounting Task (DDT) and the Cambridge Gambling Task (CGT). Joint modeling combines the models for the two tasks into a hierarchical Bayesian structure, allowing the tasks' data to mutually inform one another's parameter estimates. Consistent models that measure the same construct should yield more precise estimates given more data (Turner et al., 2013); however, we found that, when connecting the parameters of the DDT and CGT according to the joint model (with N = 399), adding more data yielded less precise estimates for both tasks. Using the Savage-Dickey method of Bayesian model comparison, we found that a 1-factor model - which assumes the tasks are connected to the same construct of impulsivity - fared worse than a 2-factor model, which assumes that the tasks are unrelated. We also observed that DDT parameters related more closely with personality measures of impulsivity, while CGT parameters related more to response inhibition. We conclude that, while both tasks measure impulsivity, each task measures a different neurocognitive dimension of the impulsivity construct.

Numerical cognition (Drummond West & Center)

Using Occam's razor and Bayesian modelling to compare discrete and continuous representations in numerosity judgements

Author(s): Spicer, Jake; Sanborn, Adam (University of Warwick, United Kingdom). *Contact:* j.spicer@warwick.ac.uk. *Abstract:* Previous research has suggested that numerosity judgements are based not just on perceptual data but also past experience, and so may be influenced by the form of this stored information. The representation of such experience is unclear, however: numerical data can be represented by either continuous or discrete systems, each predicting different generalisation effects. This study therefore contrasts discrete and continuous prior formats within numerical estimation using both direct comparisons of computational models using these representations and empirical contrasts exploiting different predicted reactions of these formats to uncertainty via Occam's razor. Both computational and empirical results indicate that numerosity judgements rely on a continuous prior format, mirroring the analogue approximate number system, or 'number sense'. This implies a preference for the use of continuous numerical representations even where both stimuli and responses are discrete, with learners seemingly relying on innate number systems rather than symbolic forms acquired in later life.

Modeling Judgment Errors in Naturalistic Numerical Estimation

Author(s): Zou, Wanling; Bhatia, Sudeep (University of Pennsylvania, United States of America). *Contact:* wanlingz@sas.upenn.edu. *Abstract:* We quantitatively modeled and compared two types of errors in numerical estimation for naturalistic judgment targets: mapping errors and knowledge errors. Mapping errors occur when people make mistakes reporting their beliefs about a particular numerical quantity (e.g. by inflating small numbers), whereas knowledge errors occur when people make mistakes using their knowledge about the judgment target to form their beliefs (e.g. by overweighting or underweighting cues). We fit mapping error models and knowledge error models separately to predict participant estimates. Mapping error models are non-linear mappings from correct answers to participant estimates, while knowledge error models transform high dimensional word vectors representing semantic knowledge of judgment targets into participant estimates through a weight vector. In study 1, involving estimates of the calories of common food items and estimates of infant mortality rates in various countries, we found that knowledge error models predicted participant estimates with very high out-of-sample accuracy rates, significantly outperforming the predictions of mapping error models. In study 2, we used a free association task to further examine the objects and concepts that were identified by the knowledge error models as most associated with incorrect estimates, shedding light on the psychological underpinnings of numerical judgment.

Active Learning for a Two-Dimensional Number-Line Task

Author(s): Lee, Sang-Ho; Kim, Dan; Opfer, John; Pitt, Mark; Myung, Jay (The Ohio State University, United States of America). *Contact:* lee.7285@osu.edu. *Abstract:* The number-line task is a widely used task in diverse fields of study. In the task, a given number that varies every trial is estimated on a continuum flanked with 0 and an upper-bound number. An upper-bound of a number-line is often arbitrarily selected by researchers, although this design variable has been shown to affect the non-linearity in estimates. Examining estimates of varying given numbers (dimensions 1) with varying upper-bound numbers (dimension 2) can be costly because adding a new design dimension into a number-line task could drastically increase the number of trials required for examining the underlying representation of number. The present study aims to conduct a two-dimensional number-line task with the given number and the upper-bound being the design variables. A design optimization algorithm, Gaussian Process Active Learning (GPAL), made this new paradigm feasible without increasing the number of trials, by presenting only the most informative combinations of the design variables

every trial. Our experimental data showed that the non-linearity of the number-line estimates increases with the upper-bound of the number line. The degree of non-linearity could predict a math skill (i.e., addition proficiency), but only when the upper-bound was relatively large. The observed range-dependency of the number-line estimates would not be fully explored without systematically manipulating the upper-bound as an additional design variable. As in the present two-dimensional number-line task, GPAL would be a useful tool for the research problems that require multidimensional design experiments to be solved.

Monotonicity, Convexity, Continuity & Analogy - the Psychological Scaffolding of Arithmetic

Author(s): Grice, Matt; Kemp, Simon; Morton, Nicky; Grace, Randolph (University of Canterbury, New Zealand). *Contact:* gricematt@myvuw.ac.nz. *Abstract:* Grace et al. (2018) showed that observers responded based on both differences and ratios of stimulus magnitude in an implicit, non-symbolic perceptual comparison task. These findings raise the question of whether differences and ratios are afforded a privileged status in quantitative judgement. We present mathematical evidence that addition and multiplication (being the complements of differences and ratios, respectively) - of natural, rational, and real quantities - are structurally unique operations among all possible binary operations on the naturals, rationals, and reals. Moreover, the structural uniqueness is obtained via innocuous principles; namely, those of monotonicity, convexity, continuity, and isomorphism (MMCI). From the psychological literature, several lines of evidence suggest that these four principles (MCCI)—prior to their mathematical existence—enjoy a fundamental psychological existence, and inform perceptual judgements across a range of phenomena. Here we argue that they are also sufficient for the development of the building blocks of mathematical thought.

ICCM track 6 (Drummond East)

A Skill-based Approach to Modeling the Attentional Blink *Author(s):* Corne Hoekstra, Sander Martens and Niels Taatgen

Less is More: Additional Information Leads to Lower Performance in Tetris Models *Author(s):* Catherine Sibert, Jacob Speicher and Wayne Gray

Predicting Performance in Cardiopulmonary Resuscitation *Author(s):* Kevin Gluck, Michael Collins, Michael Krusmark, Florian Sense, Sarah Maass and Hedderik van Rijn

ACT-R model for cognitive assistance in handling flight deck alerts *Author(s):* Oliver Klaproth, Marc Halbrgge and Nele Ruwinkel

Monday, July 22, 2019, morning

Methods 1 (Ballroom West)

Potential Contributions of Clinical Mathematical Psychology to Addressing the Crisis of Confidence in Psychological Science

Author(s): Neufeld, Richard Jim; Cutler, Colleen Diane (western university, Canada). *Contact:* rneufeld@uwo.ca. *Abstract:* The “Crisis of Confidence in Psychological Science” comprises a shaken security about the reliability of truth claims. The field of formal modeling has responded to this crossroads in part through a forthcoming special issue of Computational Brain and Behavior on “Robust Practice in Quantitative Modeling”. The area of clinical mathematical psychology arguably stands as a potential resource for addressing robustness of quantitative models. Examples include the following: Busemeyer-Wang model generalization testing, according to model transferability to extreme individual differences afforded by clinical samples (including abductive applicability to ample secondary data, from the clinical literature); providing “solution-oriented” model support, by adding to the body of clinical-assessment technology through methods of cognitive modeling of individual symptom-significant cognitive functioning, and evaluating cognitive-performance aspects of CNS-directed pharmaceutical regimens; providing a cognitive-function anchoring for clinical cognitive neuroscience (redressing “Poldrack reverse logic”); disclosing cognitive neuro-imaging deviations co-extensive with cognitive-performance abnormalities; providing a cognitive-function linchpin for different levels of clinical cognitive neuroimaging; and demonstrating the value of Bayesian provision for clinically-imposed small-N model testing, and performance over-dispersion. Each potential contribution is illustrated with examples from the literature.Practical strategies for tapping this set of possibilities are presented.

Traps and tricks in Monte-Carlo simulation-based parameter estimation of advanced mathematical models

Author(s): Li, Yiqi; Schlather, Martin; Erdfelder, Edgar (University of Mannheim, Germany). *Contact:* yili@mail.uni-mannheim.de. *Abstract:* Mathematical models applied in psychology and cognitive science have become more and more sophisticated, taking complex psychological processes and the interactions between them into account. For newly developed mathematical models, established methods for statistical inference that can be applied directly are not necessarily available. Often, the model cannot be described analytically so that numerical methods based on Monte-Carlo simulation are required to obtain model predictions such as the density function. Fitting such models can be challenging and the modeler may be confronted with a series of problems. These problems usually fall into two categories: extensive computation time and identifiability issues. Pursuing the goal of reducing computational intensiveness as well as numerically undesirable phenomena, we promote programming strategies and techniques to diagnose and resolve diverse kinds of problems. Regarding computation time, we demonstrate that some seeming trifles, such as the choice of the programming language, the design of the simulation study and the storage and management of intermediate results, can actually have a significant influence on the speed. In contrast, parallel computing and vectorization do not always yield a gain, depending on the modeling problem and the implementation. Low computational expense facilitates the detection and rectification of identifiability issues, such as ill-conditioning, correlations among parameters, and over-parameterization. We show that numerical undesirable characteristics can arise artificially from unsuitable use of random seeds and the way in which random numbers are generated and assigned. We also discuss how reparameterization and profiling can yield

proper box constraints, solve convergence problems, and reduce dependency of the results on starting values. Furthermore, we present an algorithmic procedure for the case of fitting a model to multiple datasets collected under different experimental conditions, whereby some of the parameters are assumed to depend on these conditions while others to be invariant to them. We explain our approaches using the example of a queueing model of visual search (Li, 2018). In conclusion, an optimal application of carefully chosen numerical and programming strategies and techniques can speed up the parameter estimation process by a factor of 100 and lead to more stable and more accurate estimates.

Fundamental Tools for Deriving Likelihood Functions for ACT-R Models

Author(s): Houpt, Joseph[(1)]; Fisher, Christopher[(2)]; Gunzelmann, Glenn[(2)] (1: Wright State University, United States of America; 2: United States Air Force Research Laboratory). *Contact:* joseph.houpt@wright.edu.
Abstract: ACT-R is a popular framework for developing, simulating and testing comprehensive theories of cognition. In many applications, inferences supported by ACT-R models are based on comparing Monte Carlo simulations to observed data rather than measures based on the likelihood of the data (such as the various information criteria). In this presentation, we demonstrate the fundamental tools for developing models of ACT-R within a statistical framework. Instantiating ACT-R in a statistical framework has many advantages, including facilitating the use of modern parameter estimation and model comparison techniques, allowing direct comparison between ACT-R and other closed-form models, increased computational efficiency, facilitating real-time application of ACT-R models, and giving the ability to perform a deeper mathematical analysis of model properties. We will demonstrate the use of these tools with several model variants of the classic fan experiment, beginning with a simple baseline model of ACT-R's declarative memory system and progress through increasingly complex sub-models. Our goal is that this work will continue to bridge between the mathematical psychology community and the ACT-R community and facilitate new and exciting research.

Variational Bayesian Methods for Cognitive Science

Author(s): Galdo, Matthew; Bahg, Giwon; Turner, Brandon (The Ohio State University, United States of America). *Contact:* brendan.m.galdo@gmail.com. *Abstract:* Bayesian inference has become a powerful and popular technique for understanding psychological phenomena. However, compared to frequentist statistics, current methods employing Bayesian statistics typically require time-intensive computations, often hindering our ability to evaluate alternatives in a thorough manner. Here, we advocate for an alternative strategy for performing Bayesian inference, called variational Bayes (VB). VB methods posit a parametric family of distributions that could conceivably contain the target posterior distribution, and then attempt to identify the best parameters for matching the target. In this sense, acquiring the posterior becomes an optimization problem, rather than a complex integration problem. VB methods have enjoyed considerable success in fields such as neuroscience and machine learning, yet have received surprisingly little attention in fields such as psychology. Here, we identify and discuss both the advantages and disadvantages of using VB methods. In our consideration of possible strategies to make VB methods appropriate for psychological models, we develop the Differential Evolution Variational Bayes algorithm, and compare its performance to a widely used VB algorithm. As a test problem, we evaluate the algorithms on their ability to recover the posterior distribution of the Linear Ballistic Accumulator model. Although we cannot endorse VB methods in their current form as a complete replacement for conventional methods, we argue that their accuracy and speed warrant inclusion within the psychologist's toolkit.

Methods 2 (Ballroom West)

Bayes Factors for Determining the Dimensionality of Psychological Multidimensional Scaling Representations

Author(s): Gronau, Quentin F.[(1)]; Lee, Michael D.[(2)] (1: University of Amsterdam; 2: University of California Irvine). *Contact:* Quentin.F.Gronau@gmail.com. *Abstract:* Multidimensional scaling (MDS) was developed starting in the 1950s in cognitive psychology, as a statistical method for making inferences about human mental representations. MDS typically models the similarities or psychological proximities between pairs of stimuli, representing each stimulus as a point in a multidimensional space, such that more similar stimuli are nearer each other. The core psychological motivation is that the similarities reflect the basic cognitive process of generalization. A foundational challenge in MDS modeling is determining the dimensionality of the representational space. Here we present a principled Bayesian approach for determining the dimensionality of the representational space. This approach requires the development of a joint prior distribution on the representational points that imposes constraints to make the MDS model identifiable. These constraints depend on the Minkowskian metric. We discuss a set of constraints for the Euclidean case and we point out a few issues with the city-block case. Based on these priors, for the Euclidean case, we discuss how to determine the dimensionality of the MDS representation using Warp-III bridge sampling (Meng & Schilling, 2002).

Toward a principled Bayesian workflow in cognitive science

Author(s): Schad, Daniel J.[(1)]; Betancourt, Michael[(2)]; Vasishth, Shravan[(1)] (1: University of Potsdam, Germany; 2: Symplectomorphic, New York, USA). *Contact:* danieljschad@gmail.com. *Abstract:* Experiments in research on memory, language, and in other areas of cognitive science are increasingly being analyzed using Bayesian methods. This has been facilitated by the development of probabilistic programming languages such as Stan, and easily accessible front-end packages such as brms. However, the utility of Bayesian methods ultimately depends on the relevance of the Bayesian model, in particular whether or not it accurately captures the structure of the data and the data analyst's domain expertise. Even with powerful software, the analyst is responsible for verifying the utility of their model. To accomplish this, we introduce a principled Bayesian workflow (Betancourt, 2018) to cognitive science. Using a concrete working example, we describe basic questions one should ask about the model: prior predictive checks, computational faithfulness, model sensitivity, and posterior predictive checks. The running example for demonstrating the workflow is data on reading times with a linguistic manipulation of object versus subject relative sentences. This principled Bayesian workflow also demonstrates how to use domain knowledge to inform prior distributions. It provides guidelines and checks for valid data analysis, avoiding overfitting complex models to noise, and capturing relevant data structure in a probabilistic model. Given the increasing use of Bayesian methods, we aim to discuss how these methods can be properly employed to obtain robust answers to scientific questions.

How informative are uninformative priors?

Author(s): Kennedy, Lauren Ashlee[(1)]; Simpson, Daniel[(2)]; Gelman, Andrew[(3)] (1: School of Social Work, Columbia University; 2: Department of Statistical Sciences, University of Toronto; 3: Statistics and Political Sciences, Columbia University). *Contact:* lauren.kennedy729@gmail.com. *Abstract:* Complex psychological processes require complex generative models. Complex models often have a number of hyper-priors that are far removed in the model to the observed data. Although sometimes these priors have an intuitive interpretation of what would be uninformative, oftentimes uninformative priors are used instead. However, recent in Bayesian statistics suggests that often what are considered to "uninformative" are actually quite informative. At best this can cause computational difficulties, but at worst this can potentially bias parameter

and model selection estimates. This is rarely trivial to see from manual inspection of the model likelihood and priors, but instead the two have to be interpreted together. One solution to this issue that is growing increasingly popular are prior predictive checks. In this talk we demonstrate with applications from cognitive science the relative information of common uninformative priors in terms of the expected data using PPCs and other simulation based approaches.

Toward a General-Purpose Methodology for Adaptive Design Optimization of Cognitive Modeling Experiments

Author(s): Kim, Woojae (Howard University, United States of America). *Contact:* wjaekim.1124@gmail.com.
Abstract: A fundamental problem of computational cognition is that the level of detail with which a cognitive model attempts to describe behavior demands 'as much' detail in supporting data. As observations in controlled experiments are often expensive (e.g., child subject, costs of MRI scans), this is a rather significant barrier. The method of adaptive design optimization (ADO) has been proposed as a solution: It can optimize experimental manipulation (e.g., selection of stimuli) for maximized inference. It would enable cognitive scientists to probe quantitative stimulus-response relationships, possibly on a multidimensional domain, in a way that would be otherwise intractable due to impractical task loads. Despite its groundbreaking potential for cognitive modeling research, ADO is out of reach for most researchers in the field. The formidable task of its implementation for each new experimental paradigm is a stumbling block to the methodology's promising power being realized and duly appreciated. A step toward breaking this state is to make a general-purpose methodology available. To that end, the present research develops a working prototype of an ADO software package. The focus of initial development is on the treatment of models with known likelihoods and static parameters of arbitrary dimensions. The features, application examples, and implications of the software are discussed.

Symposium on Organizational Principles of Vision (Salons 6 & 7)

Skewed Crystallographic Groups and Their Impact on Perception

Author(s): Liu, Yanxi (Penn State University, United States of America). *Contact:* yanxi@cse.psu.edu.
Abstract: Affinely skewed crystallographic groups have a theoretically and computationally desirable property of self-closeness. Under arbitrary affine transformations, little is known on their "migration paths" or their clique-like "family trees". I will demonstration our exploration of periodic patterns' reorganization in terms of their symmetry groups (crystallographic groups) under affine deformation, and the surprising insights the outcome of this finding will bring to machine and human visual perception.

Single-View Gestalt 3D Manhattan Surface Reconstruction

Author(s): Elder, James[(1)]; Qian, Yiming[(1)]; Ramalingam, Srikumar[(2)] (1: York University, Canada; 2: University of Utah, USA). *Contact:* jelder@yorku.ca. *Abstract:* We live in a 3D world and we perceive it as such. Human 3D perception derives in part from stereopsis and motion parallax, but it persists even when the input is a single image or at distances where stereopsis and motion cues are weak. How does the brain do this? Recent deep-learning algorithms show that it is possible to teach a network to recover rough 3D range from a single image, but these systems fail to capture the crisp structures that humans perceive, and with millions of free parameters provide little insight into the physics, geometry and computational principles that underpin monocular 3D perception. Unlike stereo and motion parallax, linear perspective does not weaken with distance, depending only on visual angle. Since the early Renaissance, artists have relied upon linear

perspective to produce compelling 3D impressions from 2D canvases. The volumetric quality of these renderings increases from one- to two- and three-point perspective, highlighting the importance of rectilinear (Manhattan) regularities, and recent neuroscience has revealed localized areas of the brain specialized for the processing of this rectilinear structure. Here I will describe a computational model for single-view 3D Manhattan reconstruction inspired by these findings. The model comprises a feed-forward network of modules representing progressively more global 2D and 3D structure through repeated application of Gestalt principles: from edges to 3D line segments, 3D junctions, local 3D scaffolds and ultimately complete 3D rectilinear polyhedra. The model has no free parameters, requires no training, and outperforms state-of-the-art deep learning approaches.

Depth from stereo when oculomotor information is, and is not, required

Author(s): Sawada, Tadamasa (Higher School of Economics, Russian Federation). *Contact:* tada.masa.sawada@gmail.com. *Abstract:* Our perception of depth is quite reliable under natural 3D viewing conditions when eye movements are present. Binocular disparity is often believed to be one of the most important cues for perceiving depth. Many also assume that the visual system must know the relative orientation of the eyes to perceive depth from binocular disparity. But note that depth perception, based on disparity, has usually been studied under laboratory conditions with very simple, unnatural visual stimuli. All of these experiments showed that depth perception was slow, unreliable, and distorted systematically. These results are in conflict with our everyday life experience where depth perception is fast, reliable and stable even when our eyes move. This conflict was addressed by developing a computational model, which does not use any oculomotor information, whatsoever, to recover depth from a stereo-pair of retinal images. This recovery is based entirely on the geometry of the optics of the eyes as long as the stereo retinal images used are not degenerate. Note that many of the visual stimuli used in prior laboratory studies can be considered to be degenerate because this model cannot recover depth from these visual stimuli if oculomotor information is not provided. This result suggests that the role binocular disparity has been shown to play in depth perception may be confined to the unnatural conditions usually favored in the laboratory.

Geometrical knowledge used in 3D scene inferences

Author(s): Zaidi, Qasim[(1)]; Koch, Erin[(2)]; Maruya, Akihito[(1)] (1: State University of New York, United States of America; 2: California Institute of Technology, United States of America). *Contact:* qz@sunyopt.edu. *Abstract:* Projective geometry describes the mapping of 3D scenes to retinal images. Correctly judging poses, sizes and shapes of objects are functionally important components of scene understanding for biological and machine visual systems. If humans exploit projective geometry in estimating these properties, it could answer the age-old question about geometry being innate to the human mind. A 3D object seen from different views forms quite different retinal images, and many different 3D objects can form identical retinal images, so inferences based solely on retinal information are underspecified. However, the very frequent projection of objects on the ground to retinal images is a 2D-to-2D mapping, described by an invertible trigonometric function. Hence using the back-transform derived by inverting the projection function would lead to veridical inferences. We show that human observers consistently apply the optimal back-transform for pose inferences in 3-D scenes and obliquely viewed pictures of 3D scenes. This leads to veridical estimates for 3D scenes, albeit with a systematic fronto-parallel bias, but illusory rotation of pictured scenes wrt to the observer. For estimating relative sizes, observers' generally correct projective distortions according to the optimal back-transform, except for poses close to the line of sight. Size underestimation increases with object length, which we show is due to an overestimation of viewing elevation. Further, objects seen as unbroken and cohesive suggest that prior assumptions incorporate geometrical properties invariant under perspective projection, such as continuity, collinearity and convergence. Humans thus seem to have internalized particular

aspects of projective geometry through evolution or learning.

Visual constancy and veridicality are explained by symmetry

Author(s): Pizlo, Zygmunt (University of California, Irvine). *Contact:* zpizlo@uci.edu. *Abstract:* Physical objects in our environment are characterized by many permanent characteristics, including their size, mass, shape, rigidity or piecewise rigidity, part-whole relationship, surface reflectance, and the elasticity of objects and the viscosity of fluids. The permanence (invariance) of physical objects is the result of the Laws of Physics, which are also characterized by invariance (symmetry) under a variety of transformations, for example, spatial translation and rotation, as well as temporal translation. It seems completely natural to assume that our visual system's most fundamental function is to detect and represent the permanent characteristics of the objects that are present in our natural environment. This function, which has been called "perceptual constancy", has been studied for at least a millennium (starting with Alhazen in 1083 CE), but all prior efforts have attempted to discredit the concept called perceptual constancy completely, or to document its partial failures. This paradoxical disconnect between invariance as it is recognized and used in the physical environment and how invariance is used in perceptual representations could result from the absence of a theory that can describe, perhaps even explain, how invariant percepts are produced from invariant objects. In this talk, I will describe the first theory of visual constancy and veridicality, in which the invariant visual representation takes the form of a conservation that results from applying a least-action (simplicity) principle to the symmetries of objects, in much the same way that Emmy Noether (1918) derived the Conservation Laws in Physics from the symmetries of the Natural Laws.

On the Projective Geometry of Binocular Space

Author(s): Zhang, Jun (University of Michigan, United States of America). *Contact:* junz@umich.edu. *Abstract:* Binocular vision involves the projection of objects in the 3-D visual space onto the two retinae and the comparison of spatial layout of objects in these retinal half-images. Here we characterize the unitary representation of the binocular space as a complex half-plane from the perspective of the cyclopean eye. We then investigate its automorphism group, namely the Möbius transformation group, and the associated invariants when the two eye positions are treated as fixed points of the automorphism. A three-point simple ratio from an object point to both eyes is constructed; as a complex number, its angle measures the difference in azimuth of the projected rays from the object point to each eye (i.e., horizontal disparity) while its modulus measures the ratio of the distances of the object point to the two eyes (i.e., relative vertical magnification or vertical size ratio). The four-point cross-ratio of two such simple ratios, as the only four-point invariant under Möbius transforms, reflects the fact that the relative disparity between any two object points remains unchanged when the eyes change fixation. Since the complex half-plane is biholomorphically equivalent to an open unit disk, both Poincaré model and Klein-Beltrami model give rise to a hyperbolic geometry, consistent with the empirically supported Luneburg's (1947; 1950) model of binocular geometry (for the depth plane). Finally, the hyperbolic tangent function $f(z) = \tanh(z)$, with inverse $f^{-1}(z) = \frac{1}{2}\log\left(\frac{1+z}{1-z}\right)$, is shown to act as the psychophysical function relating the physical representation of the binocular space to its cyclopean representation.

Accumulator models 2 (Drummond West & Center)

A Dynamic Dual Process Model of Intertemporal Choice

Author(s): Diederich, Adele[1]; Zhao, Wenjia Joyce[2] (1: Jacobs University, Germany; 2: University of Pennsylvania). *Contact:* a.diederich@jacobs-university.de. *Abstract:* Dual process theories of decision making describe choice as the product of an automatic System 1, which is quick to activate but behaves impulsively, and a deliberative System 2, which is slower to activate but makes decisions in a rational and controlled manner. However, most existent dual process theories are not mathematically specified, and thus do not generate testable qualitative and quantitative predictions. In this paper we describe a dynamic dual process model framework of intertemporal choice. This model assumes that the two systems operate sequentially to make a decision and can make precise predictions regarding choice probability and response time distributions. Using simulation studies, we illustrate how different factors (timing of System 1, time constraint, and preferences in both systems) influence model predictions. Our modelling framework provides a mathematical approach that may bring novel insights regarding the processes underlying intertemporal choices.

Changing attitudes towards uncertainty with time pressure

Author(s): Wu, Charley M.[1]; Schulz, Eric[2]; Gerbaulet, Kimberly[1,3]; Pleskac, Timothy J[1,4]; Speekenbrink, Maarten[5] (1: Max Planck Institute for Human Development; 2: Harvard University; 3: Osnabrück University; 4: University of Kansas, United States of America; 5: University College London). *Contact:* cwu@mpib-berlin.mpg.de. *Abstract:* How does time pressure influence attitudes towards uncertainty? Given constraints on the available decision time, do people reason about uncertainty differently and perhaps utilize different strategies for exploration? We manipulate decision time (unlimited vs. 400 milliseconds) across a variety of four-armed bandit tasks with reward distributions chosen to disentangle differences in expected value from differences in uncertainty. Through multiple behavioral and model-based analyses, we show that attitudes towards uncertainty are influenced by time pressure. Given unlimited time, participants were positively influenced by both high rewards and high uncertainty, consistent with previous theories incorporating an “uncertainty bonus”. But given only 400 milliseconds to make each decision, participants responded by changing their behavior to actively avoid uncertainty. Moreover, larger relative differences in uncertainty between options slowed down reaction times and dampened the drift rate of a linear ballistic accumulator model. Both of these effects were stronger under time pressure than without. These results are a useful probe into how learning and exploration strategies are influenced by computational limitations (either internally or externally imposed), and shed new light on the differential effect of uncertainty and time pressure on human exploration.

Urgency, Leakage, and the Relative Nature of Information Processing in Decision-making

Author(s): Holmes, William[1]; Trueblood, Jennifer[1]; Evans, Nathan[2]; Heathcote, Andrew[3] (1: Vanderbilt University; 2: University of Amsterdam; 3: University of Tasmania). *Contact:* william.holmes@vanderbilt.edu. *Abstract:* Over the last decade, there has been a robust debate in decision neuroscience and psychology about what mechanism governs the time course of decision making. Historically, the most prominent hypothesis is that neural architectures accumulate information over time until some threshold is met, the so-called Evidence Accumulation hypothesis. However, most applications of this theory rely on simplifying assumptions, belying a number of potential complexities. Is stimulus information perceived and processed in an independent manner or is there a relative component to information processing? Does urgency play a role? What about evidence leakage? While the latter questions have been the

subject of recent investigations, most studies to date have been piecemeal in nature, studying one aspect of the decision process or another. Here we develop a modeling framework, an extension of the Urgency Gating Model, in conjunction with a changing information experimental paradigm to jointly probe these aspects of the decision process. Using state-of-the-art Bayesian methods to perform parameter-based inference, we demonstrate 1) information processing is relative with early information influencing the perception of late information, 2) time varying urgency and evidence accumulation are of roughly equal importance in the decision process, and 3) leakage is present with a time scale of 250ms. This is the first such holistic study to utilize a changing information paradigm to jointly and quantitatively estimate the temporal dynamics of human decision-making.

The Temporal Dynamics of Task Switching: A Computational Analysis of Practice and Age Effects in Large-Scale Cognitive Training Data

Author(s): Steyvers, Mark[(1)]; Hawkins, Guy[(2)]; Karayanidis, Frini[(2)]; Brown, Scott[(2)] (1: University of California, Irvine, United States of America; 2: University of Newcastle, Australia). *Contact:* mark.steyvers@uci.edu.
Abstract: An important feature of human cognition is the ability to flexibly and efficiently adapt behavior in response to continuously changing contextual demands. We leverage a large-scale dataset from Lumosity, an online cognitive training platform, to investigate how cognitive processes involved in cued switching between tasks are affected by level of task practice across the adult lifespan. We develop a computational account of task switching that specifies the temporal dynamics of activating task-relevant representations and inhibiting task-irrelevant representations, and how they vary with extended task practice across a number of age groups. Practice modulates the level of activation of the task-relevant representation and improves the rate at which this information becomes available, but has little effect on the task-irrelevant representation. While long-term practice improves performance across all age groups, it has a greater effect on older adults. Indeed, extensive task practice can make older individuals functionally similar to less practiced younger individuals, especially for cognitive measures that focus on the rate at which task relevant information becomes available.

Accumulator models 3 (Drummond West & Center)

Revisiting Collapsing Bounds

Author(s): Ratcliff, Roger[(1)]; Smith, Philip[(2)] (1: The Ohio State University, United States of America; 2: University of Melbourne, Australia). *Contact:* rogerratcliff22@gmail.com.
Abstract: Recently O'Connell, Shadlen, Wong-Lin, and Kelly (2018) have argued strongly for evidence accumulation models of decision-making with collapsing bounds or urgency signals. They present some arguments based on human behavioral data, but then argue for nonstationarity boundaries or drift rates based on neurophysiological data. Conditional accuracy functions are a way of examining whether accuracy falls over the time course of processes as it would with urgency of collapsing bounds. We present evidence from both human and monkey data that show little evidence for such nonstationarity. We also present results from single and dual random walk processes (surrogates for diffusion processes) showing that paths prior to hitting a decision boundary show similar patterns to neural firing rates in monkeys. We finally review the literature on neurophysiological data and find that although the overall patterns support evidence accumulation models, there are significant differences in the patterns from individual studies.

The timed diffusive decision model

Author(s): Hawkins, Guy[1]; Heathcote, Andrew[2] (1: University of Newcastle, Australia; 2: University of Tasmania, Australia). *Contact:* guy.hawkins@newcastle.edu.au. *Abstract:* For decades, theories of decision making have assumed that decisions are triggered when a threshold level of evidence has been accumulated to inform a decision. Here, we propose a radical reinterpretation: decisions can sometimes be triggered when a sufficient amount of time has been committed to a decision. We show that the two termination mechanisms - evidence-based and time-based - can operate in a competitive race architecture, and they unify theoretical accounts of a range of decision phenomena including the speed-accuracy tradeoff, collapsing decision boundaries, and the relative speed of correct and error responses. As a consequence of the competitive architecture of the model, we eliminate the need for any decision-to-decision variability parameters that have been considered essential to the dominant theories of decision making but have been criticized as being ad-hoc in theoretical motivation and difficult to estimate.

Reconciling similarity in models of continuous report

Author(s): Kvam, Peter; Turner, Brandon (Ohio State University, United States of America). *Contact:* kvam.peter@gmail.com. *Abstract:* Two recent models of the evidence accumulation process have made it possible to predict responses and response times when decision makers are faced with a (near-)continuous span of alternatives. However, each one faces major barriers to success: the circular diffusion model (CDM; Smith, 2016) offers a truly continuous, analytically tractable joint likelihood for responses and response times, but has difficulty accounting for certain similarity relations as well as response distributions that are bimodal or multimodal. Conversely, the spatially continuous diffusion model (SCDM; Ratcliff, 2018) can predict multimodality without issue, but suffers from a lack of computational tractability and true continuity in response predictions due to its reliance on a large, discrete set of correlated accumulators. In this talk, we show that the primary difference between the models is their similarity rule - how they relate evidence for one alternative to evidence for another. By constructing the models in a geometric framework (Kvam, 2019), we show that the flexible kernel-based similarity rule from the SCDM can be reconstructed in a multidimensional version of the CDM using its cosine-based similarity structure. The resulting modified geometric CDM (GCDM) has no issue producing multimodal response distributions, and we demonstrate that it is substantially more efficient to simulate and fit than the SCDM. We show that its likelihood can be either computed analytically or approximated using simulation and kernel density estimation, and that it can recover shifts in parallel parameters in the SCDM with a simpler architecture.

Dynamic diffusion parameters and autocorrelated response times driven by reward

Author(s): Hong, Tao; Nadel, Jacob; Simen, Patrick (Oberlin College, United States of America). *Contact:* thong@oberlin.edu. *Abstract:* Response time data in two-choice perceptual decisions are often autocorrelated, indicating that decision model parameters are dynamic and have some memory of previous values. Autocorrelation of this type falls naturally out of a heuristic model we developed to maximize reward rates earned for task performance. The model uses decision bounds that decrease as a leaky integral of rewards increases. The model possesses the key explanatory features of the diffusion-decision model (DDM), and it explains how approximately reward-rate optimal human performance can be rapidly achieved in some experiments. Any sequential dependency in DDM parameters might yield autocorrelated response times, however. We therefore used a new model-fitting package, Dynamic Models of Cognition (DMC), to assess changes in decision bounds and other parameters within a sequence of trials in a task. Parameter recovery studies suggest the method is useable. Applications to empirical data suggest that decision bounds are negatively correlated with reward rates, as predicted by our heuristic model.

ICCM track 7 (Drummond East)

Towards Personalized Deceptive Signaling for Cyber Defense Using Cognitive Models *Author(s):* Edward A. Cranford, Cleotilde Gonzalez, Palvi Aggarwal, Sarah Cooney, Milind Tambe and Christian Lebiere

Predicting Individual Spatial Reasoners: A Comparison of Five Cognitive Computational Theories *Author(s):* Marco Ragni, Paulina Friemann, Enver Bakija, Novian Habibie, Yannick Leinhos, Dennis Pohnke, Yvan Satyawan, Maya Schoechlin and Rabea Turon

Different Brain, Same Prototype? Cognitive Variability within a Recurrent Associative Memory *Author(s):* Thadd Rolon-Merette, Damiem Rolon-Merette, Matias Calderini and Sylvain Chartier

On the Matter of Aggregate Models for Syllogistic Reasoning: A Transitive Set-Based Account for Predicting the Population *Author(s):* Daniel Brand, Nicolas Riesterer and Marco Ragni

ICCM track 8 (Drummond East)

Modelling alternative strategies for mental rotation *Author(s):* David Peebles

A process model of magnitude estimation *Author(s):* Greg Trafton

Discoveries of the Algebraic Mind: A PRIMs Model *Author(s):* Mark Y. Ji, Jacolien van Rij and Niels A. Taatgen

Perspectives on Computational Models of Learning and Forgetting *Author(s):* Florian Sense, Tiffany S. Jastrzembski, Michael C. Mozer, Michael Krusmark and Hedderik van Rijn

Monday, July 22, 2019, afternoon

Methods 3 (Ballroom West)

The Wisdom of Model Crowds

Author(s): He, Lisheng[(1)]; Analytis, Pantelis Pipergias[(2)]; Bhatia, Sudeep[(1)] (1: University of Pennsylvania; 2: University of Southern Denmark). *Contact:* hlisheng@sas.upenn.edu. *Abstract:* Risky choice is one of the most extensively studied domains in behavioral decision research. Over the last 70 years, numerous experiments have revealed the shortcomings of expected value and expected utility theories. In response, dozens of distinct mathematical behavioral theories have been advanced to account for observed behavioral patterns. However, there is little consensus regarding which of these models offers the best account of behavior, and it is unclear how we can combine these models to obtain novel descriptive and predictive insights regarding risky choice. In this paper we offer two solutions to this issue. First, we conduct a large-scale comparison of 58 prominent models of risky choice, using sixteen existing datasets consisting of 720 participants. This allows us to comprehensively evaluate numerous models in terms of their performance on the individual level across a range of different experimental designs. The results identify the set of best-performing models but also suggest a high degree of heterogeneity in model performance. Second, we show that each of the existing models can be seen as an "expert", which provides a unique opinion in an out-of-sample choice prediction problem, and that crowds of risky choice models can perform better than individual models alone. This suggests that different choice models may capture different aspects of the decision process and that the numerous existing models can be seen as offering complementary rather than competing accounts of individual choice behavior.

The copula approach to response inhibition modeling

Author(s): Colonius, Hans[(1)]; Diederich, Adele[(2)] (1: Carl von Ossietzky Universität Oldenburg, Germany; 2: Jacobs University Bremen, Bremen). *Contact:* hans.colonius@uol.de. *Abstract:* The ability to inhibit our responses voluntarily is an important case of cognitive control. The stop-signal paradigm is a popular tool to study response inhibition. Participants perform a response time task (go task), and occasionally, the go stimulus is followed by a stop signal after a variable delay, indicating subjects to withhold their response (stop task). The main interest of modeling is in estimating the unobservable stop-signal processing time, that is, the covert latency of the stopping process as a characterization of the response inhibition mechanism. In the independent race model, the stop-signal task is represented as a race between stochastically independent go and stop processes. Without making any specific distributional assumptions about the processing times, the model allows estimating the mean time to cancel a response. Neurophysiological studies on countermanding saccadic eye movements, however, have shown that the neural correlates of go and stop processes consist of networks of mutually interacting gaze-shifting and gaze-holding neurons, suggesting negative stochastic dependency between go and stop activations. We recently suggested a race model with perfect negative dependence between the processes based on the countermonotonicity copula (Colonius & Diederich, Psychol Review 2018). Here we consider the copula approach from a more general point of view allowing less than perfect dependency. In the stop signal paradigm, the main challenge for the copula approach is the limited observability of the stop signal processing time. Some first results and unsolved problems will be presented.

A nonparametric baseline model for conducting model checking and model comparison in one step

Author(s): Cox, Gregory Edward; Annis, Jeffrey (Vanderbilt University, United States of America). *Contact:* gregcox7@gmail.com. *Abstract:* Cognitive models are often too complex to be compared qualitatively, making quantitative model comparison an essential part of mathematical psychology. Bayes factors are a powerful and popular method for quantitative model comparison, but they only indicate the relative support among a set of models and cannot, on their own, assess the absolute quality of a model. Model checking is typically limited to graphical inspection or comparison with summary statistics and is divorced from model comparison. As a step toward unification of model checking and model comparison, we propose a nonparametric "reference" model that serves as a baseline in Bayesian model comparison. This reference model involves ideas from bootstrapping and kernel density estimation, treating the probability concentrated on each observation and the width of the region over which it is distributed as stochastic. The result is a model that assigns likelihoods to each observation but that does not incorporate any information/assumptions beyond that the data-generating distribution resembles the observed data. Any model that performs at least as well as this reference model therefore captures structure in the data and should be considered a viable candidate, such that its victory over another viable model is meaningful. The reference model is easily "plugged in" as a candidate in any likelihood-based model comparison, revealing the viability of the set of models under consideration. We illustrate the utility of this reference model in a set of toy examples as well as in a case of comparing different response time models.

Modeling (Salons 6 & 7)

Mathematical psychology in the wild - why and how? Insights from applying basic modelling concepts to applied problems in traffic safety and self-driving cars

Author(s): Markkula, Gustav (University of Leeds, United Kingdom). *Contact:* g.markkula@leeds.ac.uk. *Abstract:* Mathematical models of human perception, cognition, and behaviour provide an essential means of stringent knowledge-building in the psychological and cognitive sciences. However, these models also hold large potential value as tools in more applied contexts. What does it take to bring models out of the science lab, over to real applications, and how might this benefit both society and the involved researchers themselves? In this talk, I will first provide an overview of work by myself and collaborators on mathematical modelling of road user behaviour, with applications in traffic safety and vehicle automation. I will describe how a number of open applied questions in this domain have been mapped to existing basic scientific knowledge, including models of evidence accumulation (drift diffusion), predictive coding, and action intent recognition. I will present recent, not yet published results from this line of work, showing how especially accumulator models can be leveraged$^{(1)}$ in combination with predictive coding ideas to predict human responses to vehicle automation failures,$^{(2)}$ with EEG data to provide further insight into human decision making in traffic emergencies, and$^{(3)}$ to model the complex interplay of human (or automated) road users negotiating for space in traffic. In the second part of the talk, I will provide a more general discussion on the topic of transforming basic models into applied ones, how to go about it, and how it can lead to not only societal impact and increased research funding, but also to novel insights and advances in the basic sciences.

Making decisions on intransitivity of superiority: is a general normative model possible?

Author(s): Poddiakov, Alexander (National Research University Higher School of Economics, Russian Federation). *Contact:* apoddiakov@gmail.com. *Abstract:* The transitivity axiom (if A is superior to B, and B is superior to C then A is superior to C) often leads people to infer that A is superior to C in all cases. Yet some areas with objective intransitivity of superiority (A beats B, B beats C yet C beats A) are known: intransitive sets

of math objects (dice, lotteries in intransitive relations “stochastically greater than”), intransitive competition in biology, etc. All these intransitive relations are probabilistic. We have designed objects in deterministic intransitive relations. Intransitive machines demonstrate unexpected intransitivity in relations “to rotate faster”, “to be stronger”, etc. in some geometrical constructions - Condorcet-like compositions. Intransitive chess positions are such that Position A for White is preferable to Position B for Black (i.e., when offered a choice, one should choose A), Position B for Black is preferable to Position C for White, which is preferable to Position D (Black) – but the latter is preferable to Position A. Taking into account the variety of already known intransitive objects and systems, we pose the following problem. Based on information about the options A, ttf, and C separately, and information that A beats B and B beats C, can one conclude anything about superiority in the pair A-C? We discuss two possibilities.[(1)] Not only concrete decisions, but also a general algorithm for such inferences is possible.[(2)] A general normative model determining whether relations in various situations are (in)transitive is hardly possible. Decisions about transitivity/intransitivity are possible but inevitably context-dependent.

Why humans speed up when clapping in unison

Author(s): Lukeman, Ryan James (St. Francis Xavier University, Canada). *Contact:* rlukeman@stfx.ca.
Abstract: Humans clapping together in unison is a familiar and robust example of emergent synchrony. We find that in experiments, such groups (from two to a few hundred) always increase clapping frequency, and larger groups increase more quickly. Based on single-person experiments and modeling, an individual tendency to rush is ruled out as an explanation. Instead, an asymmetric sensitivity in aural interactions explains the frequency increase, whereby individuals correct more strongly to match neighbour claps that precede their own clap, than those that follow it. A simple conceptual coupled oscillator model based on this interaction recovers the main features observed in experiments, and shows that the collective frequency increase is driven by the small timing errors in individuals, and the resulting inter-individual interactions that occur to maintain unison.

Decision making 3 (Drummond West & Center)

Axioms and inference: a toolbox for abstract stochastic discrete choice

Author(s): McCausland, William James (University of Montreal, Canada). *Contact:* william.j.mccausland@umontreal.ca.
Abstract: I describe and demonstrate an R package, providing tools for a research project whose purpose is to help us better understand the foundations of stochastic discrete choice. The toolbox includes datasets compiled from the context effects literature, the stochastic intransitivity literature, and from some recent experiments where we observe choices from all doubleton and larger subsets of some universe of objects. It provides graphical tools illustrating likelihood function and posterior density contours, as well as regions, in the space of choice probabilities, defined by various stochastic choice axioms, context effects and other conditions. Eventually, it will provide tools for parametric and non-parametric inference subject to various combinations of discrete choice axioms, as well as the testing of said axioms.

Distinguishing between contrast models of category generation

Author(s): Liew, Shi Xian[(1)]; Conaway, Nolan[(2)]; Kurtz, Kenneth J.[(3)]; Austerweil, Joseph L.[(1)] (1: University of Wisconsin - Madison; 2: Shutterstock; 3: Binghamton University). *Contact:* liew2@wisc.edu.
Abstract: The generation of items in novel categories tends to be strongly influenced by how different they are to previously learned categories. We demonstrate how this idea of contrast can be meaningfully captured by two separate

concepts: one by exemplar dissimilarity, and another through the representativeness heuristic. While both models tend to make similar predictions under many conditions, they can be qualitatively distinguished by how people generate new categories after learning extremely widely dispersed categories. In this condition, the exemplar dissimilarity account predicts centrally-located novel categories, while the representativeness heuristic predicts novel categories along the edge of the feature space. We show how behavioral data using both bounded and boundless features reveal stronger evidence for the exemplar dissimilarity account of contrast.

Dissociating visuo-spatial and verbal working memory: As easy as ABC

Author(s): Marie, Poirier[(1)]; Yearsley, James Mathew[(1)]; Jean, Saint-Aubin[(2)]; Claudette, Fortin[(3)]; Genevive, Gallant[(2)]; Guitard, Dominic[(2)] (1: City, University of London, United Kingdom; 2: Université de Moncton, Moncton, NB, Canada; 3: Laval University, QC, Québec, Canada). *Contact:* `m.poirier@city.ac.uk`. *Abstract:* Echoing many of the themes of the seminal work of Atkinson and Shiffrin (1968), this paper uses the Feature Model to account for performance in working memory tasks. The Brooks verbal and visuo-spatial matrix tasks were performed alone, with articulatory suppression, or with a spatial suppression task; the results produced the expected dissociation. We used Approximate Bayesian Computation (ABC) techniques to fit the Feature Model to the data and showed that the similarity-based interference process implemented in the model accounted for the data patterns well. We then fit the model to data from Guérard and Tremblay (2008); the latter study produced a double dissociation while calling upon more typical order reconstruction tasks. Again, the model performed well. The findings show that a double dissociation can be modelled without appealing to separate systems for verbal and visuo-spatial processing. The latter findings are significant as the Feature Model had not been used to model this type of dissociation before; importantly, this is also the first time the model is quantitatively fit to data. For the demonstration provided here, modularity was unnecessary if two assumptions were made:[(1)] the main difference between spatial and verbal working memory tasks is the features that are encoded;[(2)] secondary tasks selectively interfere with primary tasks to the extent that both tasks involve similar features. It is argued that a feature-based view is more parsimonious and offers flexibility in accounting for multiple benchmark effects in the field.

ICCM track 9 (Drummond East)

Cognitive Models as a Computational Correlate of Theory of Mind for Human-Machine Teaming *Author(s):* Leslie Blaha

SEEV-VM: ACT-R Visual Module based on SEEV theory *Author(s):* Sebastian Wiese, Alexander Lotz and Nele Russwinkel

Lightweight Schematic Explanations of Robot Navigation *Author(s):* Robert St. Amant, Maryanne Fields, Brian Kaukeinen and Christa Robison

Poster session

Society for Mathematical Psychology posters (Ballroom Center & East)

(01) An upper bound on the maximum area under the ROC curve for pairwise comparison ranking tasks

Author(s): Funk, Patrick; Davis, Alex; Dewitt, Barry (Carnegie Mellon University, United States of America). *Contact:* pfunk@andrew.cmu.edu. *Abstract:* A fundamental assumption of judgment studies is that decision-makers are able to consistently rank events in terms of their relative likelihoods. Decision-makers may fail to construct a total order in many ways. One characterization of that failure is the minimum number of judgments that must be reversed to produce a total order. In the case of complete pairwise comparison ranking tasks (tournaments), that minimum number is called the minimum feedback edge (arc) set. We prove that the maximum possible area under the ROC curve for a pairwise comparison ranking task is equivalent to the cardinality of the minimum feedback edge set for a tournament graph. The result allows researchers to upper bound the skill of a judge without any criterion information. We then explore the conditions under which aggregation based on the maximum possible AUROC leads to better performance than equal weighting.

(02) Induction of troubleshooting strategies using visual aids in a computerized digital network task

Author(s): Bordewieck, Martin; Elson, Malte (Ruhr-University Bochum, Germany). *Contact:* martin.bordewieck@rub.de. *Abstract:* Reverse engineering refers to the process of extracting knowledge from a system in order to enable recreating it and is essential, among other things, in infringing intellectual property in the chip industry. In addition to automatic tools used to this end, the problem-solving processes of fault diagnosis, debugging or troubleshooting are crucial for reverse engineering, when tools fail and manual intervention is required, e.g. due to protective measures implemented in a system. Reverse engineers or hackers are likely to have particularly profound problem-solving skills of this kind. The aim of the presented project is therefore to investigate these specific competences applying a paradigm that sheds light on cognitive processes critical to hacking. In a first step, the presented study examines strategies participants from a general sample use under different conditions in a computerized digital network task and assesses cognitive variables, which predict troubleshooting performance. Participants are asked to identify faults in simplified abstract networks using colored markers as visual aids. Experimentally varied instructions for marker use are hypothesized to induce different more or less efficient troubleshooting strategies. Since the applied stimulus material and the utilization of visual aids match important aspects of hackers' thinking and cognitive variables probably correlated with troubleshooting and hence possibly also with hacking performance are assessed the study will provide significant insight into the psychology of hacking. The study design will be presented as well as first results.

(03) The Psychology of software reverse engineering and obfuscation

Author(s): Hamadache, Salsabil[(1)]; Elson, Malte[(2)] (1: Ruhr University Bochum, Germany; 2: Ruhr University Bochum, Germany). *Contact:* salsabil.hamadache@rub.de. *Abstract:* In software development, obfuscation techniques are used to deliberately create code that is difficult for humans to comprehend. Their goal is to hamper reverse engineering, the process of identifying a system's components, interrelationships, and functionality, which may be attempted for both legitimate and illegitimate reasons. Technical obfuscation

and reverse engineering procedures in IT security are fairly understood, but little is known about the human sense-making necessarily involved or the role of adversarial reasoning in IT security. Both obfuscation and reverse engineering can be conceptualized as psychological problem solving processes. We will conduct a study to receive insights into strategies and challenges when obfuscating and reverse engineering code. Having derived potential predictors of performance from the problem solving literature (convergent/divergent thinking, ambiguity tolerance, adversarial reasoning), we will empirically assess their relevance in this domain. In a between-subjects experimental design, participants will be randomly assigned to receive a course on adversarial reasoning (or none), then will either be given clear code that they will be asked to obfuscate, or to reverse engineer clear software code and code that has been obfuscated by another participant. The goals of this research are twofold: gaining insight into fundamental adversarial problem solving processes, and improving our understanding of what makes reverse engineering of software code particularly hard (or easy). In a talk at MathPsych, we want to report our findings and implications as well as the intterelation between reverse engineering and mathematical thinking and computational thinking. In future research, which we will also sketch, we will consider Boolean logic as the underlying foundation of thinking and learning in IT.

(04) A hierarchical Bayesian state trace analysis for assessing monotonicity while factoring out subject, item, and trial level dependencies

Author(s): Sadil, Patrick S.; Cowell, Rosemary A.; Huber, David E. (University of Massachusetts, Amherst, United States of America). *Contact:* psadil@gmail.com. *Abstract:* State trace analyses assess the latent dimensionality of a cognitive process by asking whether the means of two dependent variables conform to a monotonic function across a set of conditions. Using an assumption of independence between the measures, recently proposed statistical tests address bivariate measurement error, allowing both frequentist and Bayesian analyses of monotonicity (e.g., Davis-Stober, Morey, Gretton, & Heathcote, 2016; Kalish, Dunn, Burdakov, & Sysoev, 2016). However, statistical inference can be biased by unacknowledged dependencies between measures, particularly when the data are insufficient to overwhelm an incorrect prior assumption of independence. To address this limitation, we developed a hierarchical Bayesian model that explicitly models the separate roles of subject, item, and trial-level dependencies between two measures. Assessment of monotonicity is then performed by fitting separate models that do or do not allow a non-monotonic relation between the condition effects (i.e., same versus different rank orders). The Widely Applicable Information Criterion (WAIC) and Pseudo Bayesian Model Averaging – both cross validation measures of model fit – are used for model comparison, providing an inferential conclusion regarding the dimensionality of the latent psychological space. We validated this new state trace analysis technique using model recovery simulation studies, which assumed different ground truths regarding monotonicity and the direction/magnitude of the subject- and trial-level dependence. We also provide an example application of this new technique to a visual object learning study that compared performance on a visual retrieval task (forced choice part recognition) versus a verbal retrieval task (cued recall).

(05) A Quantitative Test of Transitivity in Mate Preference

Author(s): Wang, Hongyi$^{(1)}$; He, Zhilin$^{(1)}$; He, Lisheng$^{(2)}$ (1: East China Normal University, China, People's Republic of; 2: University of Pennsylvania, USA). *Contact:* hywang@psy.ecnu.edu.cn. *Abstract:* The weighting of different attributes in mate choice and preference has received much attention over decades. Men have often been found to weigh fertility-related attributes (e.g., physical attractiveness) more, but resource-related attributes (e.g., earning capacity) less, than women do in mate choice. A central, yet untested, assumption underlying the prevalent elicitations of attribute-weighting is the transitivity of preference. In this study, we attempted such a test. To achieve a highly powered test of transitivity, we designed two sets of profiles, with each consisting of five profiles of potential mates, for every participant. Each profile contains two-dimensional

information: physical attractiveness (a face image) and earning capacity (annual income). In one set, attractiveness and earning capacity were negatively correlated; in the other set, the two dimensions were positively correlated. Ten binary choice pairs were created from each set, totaling 20 unique binary choice pairs. A total of 108 male and female heterosexual participants were recruited. They were instructed to indicate their preference in each pair of potential mates as either a long-term or short-term partner (within-participant conditions). In each condition, every pair of profiles was repeated 10 times to obtain choice frequencies. We used a Mixture Model of Transitive Preference to test whether participants displayed transitivity or intransitivity in the experiment. Overall, we found that violations of transitivity in mate preference were rare, in either long-term or short-term mating context. Our results validate the assumption of transitivity in mate preference underlying the prevalent attribute-weighting elicitations.

(06) A test of systems factorial technology in nested architectures across the visual field

Author(s): Fan, Gaojie; Gamble, Heather; Rodgers, Jessica; Thomas, Robin (Miami University, United States of America). *Contact:* fang@miamioh.edu. *Abstract:* Systems Factorial Technology (SFT) was developed to study the process of how people combine and utilize information from different sources. By using a variety of non-parametric analyses such as mean interaction contrast (MIC) and survivor interaction contrast (SIC), SFT can distinguish between types of information processing architectures (mainly parallel and serial) as well as stopping rules (mainly exhaustive and self-terminating). In the current study, we try to extend the original theory to nested architectures where the performances of both hemispheres are examined. Instead of visual stimuli presented at the center or either side of people's visual fields, we are presenting visual stimuli on both the left and the right side in their vision in order to study the interaction between the two hemispheres, as well as its relationship with processing architectures. We use reaction time data to test the predicted models of various strategies and investigate what strategies people use when accomplishing different tasks.

(07) Action timing and sequencing in action video games

Author(s): Gianferrara, Pierre Giovanni (Carnegie Mellon University, United States of America). *Contact:* pgianfer@andrew.cmu.edu. *Abstract:* Anderson et al. (in press) present an ACT-R model of how humans learn to play rapid-action video games. To further test this model we have developed new measures of action timing and sequencing as predictors of performance in the context of a novel experimental paradigm named Auto Orbit (a variant of the original Space Fortress video game, Donchin, 1989; Frederiksen & White, 1989). In Auto Orbit, a ship is orbiting around a balloon at a constant speed. The player needs to learn how to adjust the ship's aim and fire missiles at the balloon under temporal constraints. In addition to the baseline condition, we investigated two conditions where we manipulated the ship's orbital speed and the game speed. To assess sequential structure, we extracted participants' keypress sequences and computed the Shannon entropy to measure their sequential predictability. To assess temporal structure, we used the autocorrelation of the shots fired and focused on the autocorrelation function's first positive peak to measure the fires' regularity (peak's amplitude) and periodicity (peak's offset from lag 0) to measure their speed. These three measures – sequential entropy, regularity, and periodicity - are reliably correlated with individual differences in the players and to learning of the video game. We will assess how well the ACT-R model can reproduce these measures in its video game play and discuss potential improvements to the model.

(08) Adaptive task selection in decision-making tasks under uncertainty for the measurement of subjective probability

Author(s): Fujita, Kazuya; Okada, Kensuke (The University of Tokyo, Japan). *Contact:* kfujita@p.u-tokyo.ac.jp. *Abstract:* Subjective probability can be measured using sequential

decision-making tasks under uncertainty. These tasks require participants to choose between a pair of gambles with known and unknown outcome probabilities, respectively. However, naive equilibrium from this approach suffers from the effect of a cognitive bias known as ambiguity aversion. To take this into account, Kilka and Weber (2001) proposed a two-stage model that incorporates cumulative prospect theory. Although this model makes it possible to investigate subjective probability under uncertainty, its parameter estimation typically requires data from many trials. In the present study, we derived the Fisher information matrix of the two-stage model, and propose an adaptive administration of decision-making tasks in which the tasks are selected to maximize the Fisher information. In a simulation study, we compared the proposed adaptive task selection method based on the Fisher information with a random task selection method. Within the adaptive task selection, we also compared the fixed rewards (e.g., Lauriola & Levin, 2007) and variable rewards designs. The results confirmed that the proposed adaptive task selection method performed much better than the random selection method and that the variable rewards design performed better than the fixed rewards design. The proposed method was then applied to the experimental data of decision-making under uncertainty. We concluded that the proposed adaptive approach based on the Fisher information is useful in efficient administration of experiments measuring subjective probability and that the proposed approach may allow us to measure subjective probability while considering ambiguity aversion.

(09) Automated cognitive modeling with Bayesian active model selection

Author(s): Lall, Vishal H.[(1)]; Suchow, Jordan W.[(2)]; Malkomes, Gustavo[(3)]; Griffiths, Thomas L.[(4)] (1: University of California Berkeley; 2: Stevens Institute of Technology; 3: Washington University in St. Louis; 4: Princeton University). *Contact:* `lall@berkeley.edu`. *Abstract:* Behavioral experiments are often feed-forward: they begin with designing the experiment, and proceed by collecting the data, analyzing it, and drawing inferences from the results. Active learning is an alternative approach where partial experimental data is used to iteratively design subsequent data collection. Here, we study experimental application of Bayesian Active Model Selection (BAMS), which designs trials to discriminate between a set of candidate models. We consider a model set defined by a generative grammar of Gaussian Process kernels that can model both simple functions and complex compositions of them. To validate the method experimentally, we use BAMS to discover how factors such as contrast and number affect numerosity judgements. We compare the rate of convergence of the active-learning method to a baseline passive-learning strategy that selects trials at random. Active learning over a structured model space may increase the efficiency and robustness of behavioral data acquisition and modeling.

(10) Bayesian cognitive and statistical modeling applied to Signal Detection Theory and the Mirror Effect in a perceptual task.

Author(s): Chávez De la Peña, Adriana Felisa[(1)]; Lee, Michael D.[(2)]; Bouzas Riaño, Arturo[(1)] (1: National Autonomous University of México, Mexico; 2: University of California Irvine). *Contact:* `adrifelcha@gmail.com`. *Abstract:* The mirror effect is a well-established empirical result in recognition memory. It shows that, when comparing subjects' responses between classes of stimuli that are differentially recognized, there are systematic differences between the identification of both targets and lure stimuli, as measured by hit and false alarm rates in signal detection theory (the implied order of the signal and noise distributions involved is what gives this pattern its name). Since the mirror effect has been predominantly tested for recognition memory tasks, most attempts to explain the observed pattern of response involves theorizing about high-level processes engaged in the study phase. To test the generalizability of this pattern to other domains where signal detection theory has been applied, we designed a perceptual task with two levels of discriminability which were defined by manipulating an optical illusion. After conducting a step by step replication of the mean-performance based analysis reported in the literature, we present evidence of the

mirror effect outside recognition memory. We then developed a more detailed model based analysis, using signal detection theory and hierarchical Bayesian methods to assess the existence of the mirror effect at both the group and individual level.

(11) Obsessive-compulsive tendency attenuates the recovery from overshadowing in associative learning

Author(s): Kunisato, Yoshihiko[(1,2)]; Sawa, Kosuke[(1)] (1: Senshu University, Japan; 2: University of Amsterdam, Netherlands). *Contact:* ykunisato@psy.senshu-u.ac.jp. *Abstract:* Obsessive-compulsive disorder (OCD) is characterized by impulsivity and disinhibition. Patients with OCD are impaired in the suppression of irrelevant memories during competitive recall (Demeter et al., 2014). We hypothesize that obsessive-compulsive tendency also attenuate the inhibitory function in a retrospective evaluation of associative learning. Five hundred thirty-two participants (260 male, 268 female, 1 intersex) from Amazon MTurk completed the online learning task and questionnaires of OCD symptoms in exchange for 4 US dollar. In the learning task (e.g. Vandorpe & De Houwer, 2005), participants were required to see the pair of food and allergic reaction and rate the causality of food and allergic reaction. We set three conditions, which includes acquisition condition (Phase 1: A+, Test: A), overshadowing condition(Phase 1: BC+, Test: B), recovery of overshadowing condition(Phase 1: DE+, Phase 2: E-, Test: D). In the overshadowing condition participants significantly lowered causality rating than in the acquisition and recovery from overshadowing condition. Our results confirmed the effect of overshadowing and recovery from overshadowing in accordance with previous studies. While the causality rating on recovery from overshadowing negatively correlated with OCD symptoms ($r = -.18 \sim -.26$), the causality rating on overshadowing did not significantly correlate with OCD symptoms ($r = -.03 \sim .01$). Our results showed that obsessive-compulsive tendency attenuates the recovery of overshadowing. However, we found that the causality rating on acquisition also negatively correlated with OCD symptoms ($r = -.23 \sim -.29$). We examine further analysis using a unifying framework encompassing Bayesian and reinforcement learning theories (Gershman, 2015).

(12) Multitask Item Response Model Revealed Bias in Estimated Emotional Features due to Response Style within the Open Affective Standardized Image Set (OASIS)

Author(s): Nomura, Keishi[(1,2)]; Kumano, Shiro[(2)]; Yotsumoto, Yuko[(1)] (1: Department of Life Sciences, The University of Tokyo, Japan; 2: NTT Communication Science Laboratories, Nippon Telegraph and Telephone Corporation, Japan). *Contact:* nomura@fechner.c.u-tokyo.ac.jp. *Abstract:* Images that evoke varied emotions associated with social and nonsocial phenomena are desired for many studies in the cognitive and behavioral sciences. To facilitate such research, several normative sets of emotional stimuli have been developed. These databases afford users the ability to explore images based on emotional ratings given by original researches. However, in those rating settings, response style–a tendency to choose specific categories regardless of content, e.g. extreme or midpoint categories–was neglected. Here, we examined potential bias due to response style in such ratings. We applied a multitask response style removal method to the Open Affective Standardized Image Set (OASIS), an open-access online stimulus set containing 900 affective images. The original ratings in the valence/arousal judgement task were modeled using task-independent response style parameters and task-dependent parameters based on item response models. We observed that: i) the model containing response style outperformed traditional item response models in terms of predictive accuracy; ii) ignoring response style led to over/underestimation of emotional characteristics of persons or items; iii) the model containing response style estimated persons' emotional characteristics with higher precision. Although affective image databases remain a powerful tool to explore emotional processing, but we strongly suggest that researchers consider response style in their rating settings or in subsequent statistical analyses.

(13) Multi-Armed Bandit Problem: A New Belief-Resilience Algorithm

Author(s): Yin, Qianbo; Hollman, Nick (University of Michigan, Ann Arbor, United States of America). *Contact:* ygrayson@umich.edu. *Abstract:* The Multi-arm bandit (MAB) problem captures a dilemma in decision-making under uncertainty. Agents are faced with n choices that have various unknown rewards where they can either exploit familiar choices with greater certainty or explore the unknown choices hoping for potentially better results. Ultimately the agents always have the goal of maximizing the total reward. Exploiting involves selecting the choice with the highest expected reward from prior information, whereas exploring involves selecting at random to gain more information about the rewards of other choices. Our research aims to develop a new algorithm to solve MAB problem, called the Belief-Resilience Algorithm. This algorithm is based on the reward estimation as well as an evaluation of how robust these beliefs are. As more information accumulates, the agent's belief becomes more robust and consequently improves how it makes decisions. We implemented the Belief-Resilience Algorithm and tested it against 5 different existing algorithms. With the parameters chosen wisely, the Belief-Resilience Algorithm outperforms several algorithms consistently. We argue that the robustness of a certain belief can play a crucial role in decision making process and this approach can potentially be a very efficiently way of solving Multi-Armed Bandit problem.

(14) Modelling individual differences in explore-exploit problems with large decision spaces

Author(s): Collignon, Nicolas; Lucas, Christopher (University of Edinburgh, United Kingdom). *Contact:* n.collignon@ed.ac.uk. *Abstract:* People frequently encounter new environments or problems where they must learn how to achieve their goals. In this work, we seek to understand how people trade off between selecting informative actions versus immediately rewarding ones when faced with novel tasks. In our experiments, participants repeatedly chose between a large number of options, obtaining rewards that were unknown functions of the options' features. We found that some people selected informative actions, efficiently discovering patterns that allowed them to maximize rewards and transfer knowledge across similar tasks. However, a consistent proportion of participants behaved sub-optimally, systematically choosing options that provided new information at the expense maximizing reward. Across four experiments, we present evidence that participants' tendency to explore was influenced by 1) how much they already knew about the underlying task structure and 2) whether their past observations remained visible. We present a modelling framework that contrasts different mechanisms for search to explain the diversity of exploratory behaviours. We use our models to better understand the systematic differences observed across individuals and across experimental conditions. Distinct groups of participants emerged in our analyses, with some activing in accordance with reward-maximizing Bayesian policies, and others adopting simple heuristics, e.g. systematically exploring adjacent options.

(15) Modeling children's sentence processing across three languages

Author(s): Etz, Alexander[1]; Priyadharshini, Veeramani[2]; Kuppuraj, Sengottuvel[3]; de Ruiter, Laura E. (4,5) (1: UC Irvine, United States of America; 2: All India Institute of Speech and Hearing, India; 3: Department of Experimental Psychology, University of Oxford, United Kingdom; 4: Department of Psychology, Tufts University, United States of America; 5: ESRC International Centre for Language and Communicative Development, University of Manchester, United Kingdom). *Contact:* etz.alexander@gmail.com. *Abstract:* Many languages allow two different clause-orders for complex sentences with adverbial clauses, e.g.[1] She jumped before she ran. vs.[2] Before she ran, she jumped. In[1], the clause order reflects the order of events in the real world (it is "iconic"); in[2], the clause order is reversed. The iconicity hypothesis states that children process complex sentences by assuming that what they hear first happens first, i.e., there is a direct mapping between the sequence of events in the linguistic form (clause order) and the sequence of events in the real world. A competing hypothesis is the frequency hypothesis, which states that children's grammatical preferences

develop according to the frequency by which they hear them. We evaluate these hypotheses using data from 26 Tamil-speaking, 34 English-speaking, and 39 German-speaking five-year-olds. Their sentence comprehension was tested with a forced-choice picture selection task, systematically manipulating clause order (subordinate-main, main-subordinate) and adverbial type (after, before, because, if). We model the data using a hierarchical Bayesian logistic regression, allowing us to estimate group-, subject-, and item-level effects of clause order, adverbial type, and their interaction for each language. The results provide strong evidence that the iconicity hypothesis holds for the average English- and German-speaking child, but that the frequency hypothesis holds for the average Tamil-speaking child. We will present a full comparison across the languages including some discussion of individual differences.

(16) Post-error speeding using an automated aid

Author(s): Mahoney, Lori; Houpt, Joseph (Wright State University, United States of America). *Contact:* mahoney.32@wright.edu. *Abstract:* Automated aids provide users additional information for making decisions on complex tasks with the goal of reducing user response time (RT) and improving accuracy. The way the aid presents the information requires the user to either make the same decision as unaided or to agree or disagree with the aid's recommendation. We measured response times and accuracy without an aid and with an aid where either: 1) the subject makes the same decision as the unaided condition, or 2) the subject agrees or disagrees with the automated aid's decision. We found decision type was a significant predictor of accuracy and RT, with a significant interaction with aid accuracy. Post hoc analysis of the data looked at the effects of previous trial correctness and its interaction with aid accuracy and decision type on accuracy and RT. Post-error speeding was present when an aid was used. We found main effects of previous trial correctness and aid accuracy on accuracy; subjects were more accurate when the previous trial was incorrect and more accurate with more accurate aids, with an interaction between previous trial correctness and aid accuracy. We also found main effects of previous trial correctness and aid accuracy on RT; subjects were slower when the previous trial was correct and slower with less accurate aids, with an interaction between previous trial correctness and aid accuracy. We also examined information accumulation rates and caution using a cognitive model.

(17) Out-of-Sample Accuracy of Weighted Additive Strategies with Limited Search

Author(s): Gula, Bartosz; Reich, Lars (University of Klagenfurt, Austria). *Contact:* bartosz.gula@aau.at. *Abstract:* In multiattribute inferences, cross-validation studies of out-of-sample accuracy have shown that fast and frugal heuristics such as take-the-best often outperform weighted additive models such as Multiple Regression, Naïve Bayes and Tally (Brigthon & Gigerenzer, 2009). From a prescriptive perspective, the results imply that decision accuracy may actually decrease when attributes are searched beyond the most valid and discriminating. Lee and Zhang (2012) showed that especially in redundant (positively correlated) environments, the evidence gained from an exhaustive search of all attributes will frequently predict the same option as the evidence gained from the frugal search of the most valid discriminating attribute. In the present study, we assessed how$^{(1)}$ simple and cognitively plausible limitations of information search (2 to 6 most valid attributes), and,$^{(2)}$ attribute redundancy, affect the relative out-of-sample performance of strategies. The strategies were cross-validated on 15 real-world data sets studied previously, and on simulated multivariate normal data with redundancy manipulated via the covariance matrix. Our results show that under high redundancy, Naïve Bayes and Tally with limited search show similar accuracy as take-the-best, whereas the letter perform relatively worse under low redundancy. We discuss the prescriptive implications for information search, search termination and information combination in multiattribute inferences.

(18) Prediction in the face of gradual and abrupt changes in the environment

Author(s): Velázquez, Carlos; Villarreal, Manuel; Bouzas, Arturo (National Autonomous University of Mexico, Mexico). *Contact:* charlyvvv@gmail.com. *Abstract:* Humans often make decisions in environments that change over time. Computational models have been developed to describe this behavior in experimental settings that vary either abrupt or gradually. However, these scenarios are almost always studied separately as well as the mechanisms that underlie behavior in them. In this work, we designed a perceptual decision-making task where participants predicted the position of a spaceship that orbited around planet Earth. Its position was generated from a Gaussian distribution with fixed variance and a mean that varied in four different ways which defined our experimental conditions. In the first condition, the mean remained stable; in the second one, it could change abruptly according to a hazard rate; in the third one, it changed gradually following a variable velocity, and in a fourth condition, the mean could change either abruptly or gradually. Our results show that subjects are able to predict the generative mean of the spaceship in the four conditions accurately and that they adjust rapidly to abrupt changes in the mean whenever they occur. We tested different models that have been proposed to describe behavior in the face of abrupt and gradual changes separately and we build a latent mixture model aiming to describe behavior in both.

(19) Retrieved-context theory of intrusive trauma memories

Author(s): Cohen, Rivka T.; Kahana, Michael J. (University of Pennsylvania, United States of America). *Contact:* rivkac@sas.upenn.edu. *Abstract:* Patients with posttraumatic stress disorder (PTSD) rate intrusive memories of the traumatic event as their most distressing symptom. Extant theories of trauma-memory intrusions propose that arousal disrupts the binding process between memories' perceptual features and their spatiotemporal contexts, resulting in fragmented voluntary memory and vivid sensory-memory intrusions. However, not all people exposed to trauma go on to develop PTSD, suggesting that encoding processes alone cannot account for who ultimately develops the disorder. Drawing upon context maintenance and retrieval (CMR) models, we develop a new computational model of intrusive memory in PTSD. We propose that during encoding, high arousal strengthens the associations between temporal context and memories' perceptual features, consistent with the eCMR model developed by Talmi et al. (2018). This lowers the threshold of similarity between encoding-retrieval contexts that is needed to cue retrieval of the trauma memory, and results in high rates of intrusions when patients encounter perceptual features that are similar to the stimuli that preceded the traumatic event. Further, we extend eCMR to include the multilist capabilities from CMR2 (Lohnas et al., 2015), enabling the operationalization of memory intrusions as prior-list intrusions of the trauma memory. We demonstrate the model's ability to simultaneously account for memory intrusions, impaired voluntary recall when there is a mismatch between trauma-context and the current retrieval context, and the efficacy of exposure-based treatments for the disorder.

(20) Risk and Emotion: Measuring the Effect of Emotions and Other Visceral Factors on Decision Making Under Risk

Author(s): Mihalicz, Michael Geoffrey (Ryerson University, Canada). *Contact:* michael.mihalicz@ryerson.ca. *Abstract:* The science of modelling choice preferences has evolved into an interdisciplinary field contributing to several branches of microeconomics and mathematical psychology. As theories in decision science and related fields mature, descriptive theories have emerged to explain systematic violations of rationality through cognitive mechanisms underlying the thought processes that guide human behaviour. Cognitive limitations are not, however, solely responsible for systematic deviations from rationality and there is a growing body of literature exploring the effect of visceral factors as the more dominant drivers. This study builds on the existing literature by investigating the impact of anger, sadness, happiness, anxiety, hunger, energy, tiredness and stress on three distinct elements that define risk preference under cumulative

prospect theory: utility, decision weights and loss aversion. By decomposing the impact of visceral factors on risk preference, I am able to provide evidence supporting the proposition that the generalized approaches to characterizing visceral factors and risk preference are too broad to be descriptively meaningful and that a portion of the variability in individual choice preferences can be explained by interacting visceral states. My findings suggest that visceral factors have the strongest effect on loss aversion, which is a major factor in how people code and evaluate financial outcomes. Anger, sadness, happiness, anxiety, energy and tiredness each affect five or more of the model parameters, while hunger and stress are significant only in their interaction with other visceral factors.

(21) Similarity in social space predicts similarity of semantic space

Author(s): Halpern, David Jacob; Rodriguez, Pedro (New York University, United States of America). *Contact:* david.halpern@nyu.edu. *Abstract:* What determines the organization of knowledge in semantic memory? Typically, memory organization is thought to depend on sensorimotor (Biederman et al. 1983) and linguistic (Steyvers et al., 2006) experience. One way to learn about what types of experience might organize semantic memory is to investigate how memory organization varies in the population. The idea that memory organization depends on sensorimotor experience is supported by studies suggesting that sub-populations such as musicians (e.g., Beilock et al., 2008) or congenitally blind subjects (e.g., Connolly et al., 2007) differ in their organization from the rest of the population. However, while these studies largely focus on a single source of variation, we might be able to discover new principles of memory organization by looking at several sources of variation simultaneously predict memory organization. Here, we look at how similarity in several demographic variables can predict similarity in memory organization. We use data from the Wisconsin Longitudinal Survey where over 5000 respondents completed semantic fluency tasks in two waves. We use LSA to find a robust similarity space in which to compare semantic fluency lists from two subjects. We show that several variables such as being closer in age, closer in political ideology, the same gender, living in the same state and being from the same family predict similarity of semantic fluency lists. We also discuss how these results might be consistent with recent proposals that emotional experience is an organizing principle of semantic memory (Vigliocco et al., 2009).

(22) Stability-Flexibility Dilemma in Cognitive Control: A Dynamical System Perspective

Author(s): Bizyaeva, Anastasia; Musslick, Sebastian; Agaron, Shamay; Cohen, Jonathan; Leonard, Naomi E. (Princeton University, United States of America). *Contact:* bizyaeva@princeton.edu. *Abstract:* Constraints on control-dependent processing have become a fundamental concept in general theories of cognition that explain human behavior in terms of rational adaptations to the limited ability to exert cognitive control. However, theories miss a rationale for why such constraints would exist in the first place. Recent computational work suggests that constraints on control can promote flexible task switching at the expense of stable task performance in the face of distraction. Here we derive an analysis of the tradeoff in a dynamical system and provide a mathematical rationale for constraints on control based on this tradeoff. We formalize control signals as potential wells, which we call attractors, and assume that constraints on control allocation limit the depth of these attractors. We study the behavior of the model in a task switching environment, in which the model is cued either to stay within the same control attractor or to switch to a different control attractor. We show that task switches correspond to alternations between two distinct perturbations of a symmetric model whose dynamical behavior is organized by a pitchfork bifurcation. We provide a formal definition of cognitive stability and cognitive flexibility and derive an intuition for their tradeoff, showing that constraints on control allocation improve cognitive flexibility but impair cognitive stability. Finally, we provide evidence that human participants adapt higher constraints on the allocation of control as the demand for flexibility increases but that participants deviate from optimal constraints.

(23) The added-value of interval-values - capturing individual response uncertainty

Author(s): Ellerby, Zack, William[(1)]; McCulloch, Josie[(1)]; Broomell, Stephen[(2)]; Wagner, Christian[(1)] (1: University of Nottingham, United Kingdom; 2: Carnegie Mellon University, USA). *Contact:* zack.ellerby@nottingham.ac.uk. *Abstract:* Quantitative survey responses are one of the most valuable and widely used tools to obtain information, from both experts and the general population. Unsurprisingly, a significant body of research has accrued relating to best practice in questionnaire design, administration and analysis. However, conventional discrete questionnaire response-formats, including both ordinal (e.g. Likert-type) and continuous (e.g. Visual Analogue) scales, are fundamentally unsuited to the direct capture of uncertainty, ambiguity or inherent-range associated with an answer. For instance, when participants select a mid-point on a discrete scale, it is unfeasible to discriminate between responses that are either indifferent, ambivalent, or uncertain. Elicitation of discrete responses can therefore discard potentially valuable information, and we propose that these approaches require respondents to collapse what might be considered their internally represented 'response-space' down to a best, but imperfect, estimate. Multiple specific points on a scale may represent a suitable response and, in some cases, selecting a range of values may be the only way to appropriately represent the actual answer. We propose an intuitive method by which respondents can more comprehensively communicate the 'response-space' – drawing an ellipse that represents an interval-valued response. This approach can efficiently capture additional information on range, ambiguity and uncertainty, enabling richer modelling and innovative analysis methods. Together, these have the potential to facilitate subsequent interpretation of these data, whilst avoiding critical information loss, for example on response uncertainty. We present findings from our research into the merits of this novel response-format; focusing on establishing added-value, and determining usability and user acceptance.

(24) The Ambiguousness of Ambiguity

Author(s): Pappas, Nick; Kellen, David (Syracuse University, United States of America). *Contact:* nrpappas@syr.edu. *Abstract:* The study of decisions under uncertainty examines people's preferences for different options when they lack information about those options. Ellsberg (1961) showed that people will prefer an option with known probabilities to an option with unknown probabilities even when these two options are mathematically equivalent. That unknown option carries a penalty due to the ambiguity of the associated probabilities. Researchers have studied attitudes towards ambiguity in different contexts, but these findings are mixed as researchers use different tasks to measure these attitudes. Therefore, we examined the effects of different tasks on ambiguity attitudes within the same participants. We elicited attitudes from participants with certainty equivalences and probability judgements. In addition, we report results that examine the effects of positive, negative, and mixed outcomes on ambiguity attitudes.

(25) The Cognitive Reflection Test Under Pressure

Author(s): Sloane, Jennifer; Liang, Garston; Donkin, Chris; Newell, Ben (University of New South Wales). *Contact:* j.sloane@unsw.edu.au. *Abstract:* The original Cognitive Reflection Test (CRT) is a widely-known three-item psychological measure which claims to test individuals on intuitive vs. analytic cognitive processing. We used a modified CRT paradigm to study the role of interruptions and time pressure on the balance of intuitive and analytic kinds of thinking. We recruited participants through Amazon's Mechanical Turk platform and they responded to a series of CRT-like questions. Every question was presented across three separate pages, and we allowed participants to go back and forth between the pages in order to re-read parts of the question. All of the questions had a multiple choice answer set, and participants selected the answer they believed to be correct. After every question, participants indicated their level of confidence on a slider ranging from "uncertain/guessing" to "absolutely certain". There were three conditions: 1) a baseline condition with no additional pressure, 2) a countdown timer condition in which participants only had a set amount of time to

answer each question, and 3) an interruption condition where participants were sometimes interrupted in the middle of attempting to solve the problems. Results showed participants did make more incorrect and intuitive responses when interrupted and under time pressure. Additionally, we found that accuracy, but not confidence, decreased when interrupted, while both accuracy and confidence decreased while under time pressure compared to baseline.

(26) The Effectiveness of Multidimensional Scaling in TSP Problems Whose Metric is not Euclidean

Author(s): VanDrunen, Jacob; Pizlo, Zygmunt (University of California, Irvine, United States of America). *Contact:* jvandrun@uci.edu. *Abstract:* It is commonly assumed that 2D images are represented as 2D Euclidean planes in the human visual system. This assumption has received support from numerous studies in which human subjects produced near-optimal Traveling Salesman (TSP) tours. Specifically, the human subjects produced TSP tours in a sequence of coarse-to-fine approximations by using a hierarchical clustering (pyramid) representation of the problem. When obstacles are introduced into a 2D Euclidean TSP, the distances between vertices are no longer Euclidean, but human subjects can still produce near-optimal tours, as long as the obstacles are geometrically simple (line segments, L, and C shapes). Can this pyramid algorithm be applied to a Euclidean approximation of the pairwise distances produced by Multidimensional Scaling (MDS), which is often the method of choice for representing cognitive spaces? In this project, we evaluated the usefulness of MDS in visual tasks in which the ground truth of the geometrical distances is known. We did this by applying a graph-pyramid algorithm, as well as the optimal Concorde algorithm to Euclidean approximations of a TSP (i.e., a TSP without obstacles) produced by MDS when MDS was applied to a TSP with obstacles. Straight line segments were used as obstacles. Errors of the pyramid algorithm and the Concorde algorithm with MDS approximations were measured in 2D, 3D and 4D spaces. The TSP solutions produced by the pyramid and the Concorde algorithm show substantial improvement between the 2D and 3D Euclidean approximations produced by MDS, but this improvement was only observed with larger TSPs.

(27) Using cognitive model parameters to interpret EEG and behavioral data

Author(s): Johnson, Joseph$^{(1)}$; McCarthy, Jim$^{(2)}$; Thomas, Robin$^{(1)}$; Russ, Bill$^{(2)}$; Asiala, Lillian$^{(2)}$; Davidson, Lauren$^{(1)}$; Pettit, Elizabeth$^{(1)}$ (1: Miami University; 2: Sonalysts, Inc.). *Contact:* johnsojg@miamioh.edu. *Abstract:* We use novel techniques for utilizing EEG and behavioral data to inform cognitive models of basic decision making. Ultimately, we aim to develop prediction algorithms for identifying mental states in real time during performance in applied tasks. Currently, we use data from EEG, choices, and response times to inform computational models that have parameters associated with interpretable mental states such as fatigue, stress, cognitive load, etc. We will combine results across four data sets that allow us to obtain parameter estimates associated with constructs such as information search, sampling, and decision in a drift diffusion model (e.g., van Vugt, et al., 2014). This allows us to draw relationships among behavioral data on performance decrements, model parameters indicating cognitive states such as level of attention, and associated neural data corresponding to well-supported assumptions about processing states. We also compare various methods (maximum likelihood, Hierarchical Bayesian; Wiecki, Sofer, & Frank, 2013; Ratcliff & Childers, 2015) in deriving parameter estimates and discuss the implications for generalizing the relationships among parameters. Finally, we will discuss how these techniques can be used ultimately to predict mental states during applied tasks (e.g. operator control) in order to adapt interface designs (e.g. information display board) or environmental factors (e.g. workload limits).

(28) Using eye gaze data to examine the flexibility of resource allocation in visual working memory

Author(s): Stewart, Edmond; Donkin, Chris; Le Pelley, Mike (University of New South Wales). *Contact:* e.stewart.1991@gmail.com. *Abstract:* Computational models of visual working memory (VWM) generally fall into two categories: slots-based and resources-based models. On the surface, these models appear to make distinct predictions. However, as these models have expanded to capture empirical data, they have begun to mimic each other. Further complicating matters, Donkin, Kary, Tahir and Taylor (2016) proposed that observers were capable of using either slot- or resource-based encoding strategies. In the current experiment, we aimed to test the claim that observers adapt their encoding strategies depending on the task environment by observing how participants move their eyes in a VWM experiment. We ran participants on a standard colour recall task (Zhang and Luck, 2008) while tracking their eye movements. Trials consisted of 3 or 6 items. We manipulated whether the number of items was held constant for a block of trials, or varied randomly. We expected to see participants use more resource-like encoding when the number of items was predictable. Contrary to these expectations, we observed no difference between blocked and unblocked conditions. Further, the eye gaze data was only very weakly related to behaviour in the task. We conclude that caution should be taken in interpreting eye gaze data in VWM experiments.

(29) Visual Detection Across the Hemispheres: Neural Correlates of Nested Architectures

Author(s): Gamble, Heather; Fan, Gaojie; Rodgers, Jessica; Thomas. PhD, Robin D. (Miami University, Oxford, OH, United States of America). *Contact:* gamblehl@miamioh.edu. *Abstract:* Systems Factorial Technology (SFT) is a response time based methodology that can reveal the structure of mental processes underlying cognitive tasks. Recently, SFT has been extended to predict patterns of response times for nested architectures potentially at work in visual detection tasks using hierarchical stimuli or compound gratings presented redundantly in both visual fields (bilateral fields, Thomas et al., 2019). In the current study, we collect EEG data in such a visual detection task designed to explore how event-related potentials (ERPs) track visual detection in the different factorial conditions, with the goal of identifying how neural activity relates to underlying cognitive architectures.

(30) Design Optimization of the Choice under Risk and Ambiguity Task Using ADOpy

Author(s): Yang, Jaeyeong[(1)]; Ahn, Woo-Young[(1)]; Pitt, Mark A.[(2)]; Myung, Jay I.[(2)] (1: Seoul National University, South Korea; 2: Ohio State University, OH). *Contact:* urisa12@snu.ac.kr. *Abstract:* Accurate and efficient inferences of empirical observations are critical for scientific inquiry. There has been a growing interest among experimental scientists in the development of formal methods for optimizing the design of experiments that lead to rapid accumulation of information about the phenomenon under study with the fewest possible measurement episodes. Our labs have recently developed and applied one such method called Adaptive Design Optimization (ADO), a Bayesian framework for optimal experimental design. Despite the potential benefits of ADO to researchers, its implementation requires expertise in statistics and computer programming. To help overcome this obstacle, we have developed an open-source Python package, dubbed ADOpy. In the present presentation, we introduce ADOpy and illustrate its application in the choice under risk and ambiguity task (Levy et al., 2010) in human experiments and also in simulations. The experimental results showed that ADO leads to substantially improved test-retest reliabilities of risk attitude and ambiguity attitude parameters, compared to those with non-adaptive methods. Further, the simulations demonstrated that the model parameters can be recovered more rapidly and accurately under ADO. We hope that the availability of ADOpy will make it easy to use the general-purpose experimental methodology at its full potential and benefit.

(31) Linking Behavioral Modeling of Intertemporal Choice and Neural Data

Author(s): Yi, Woojong; Liu, Qingfang; Turner, Bradon M. (The Ohio State University, United States of America). *Contact:* woojong.yi.525@gmail.com. *Abstract:* Intertemporal choice is decision making process of preference related to time delay and reward information. This decision can dynamically be evolved with time. In this study, we investigated the temporal dynamics of intertemporal choice. To do this interaction of delay and reward information, we designed the Multialternative Decision Field Theory (MDFT) model, which can help us understand the dynamics of intertemporal choice. Specifically, intertemporal choice can be modeled based on the accumulation processes of reward and delay information, and this accumulation can include information loss (leakage) and competition (lateral inhibition) among the intertemporal choice options. To find the best model, we compared several candidate models and selected the best model based on the information criteria. In addition to the MDFT model, electroencephalogram (EEG) can be used for its temporal dynamics of intertemporal choice. The brain activity from the EEG data can show the traces of intertemporal choice behavioral parameters related to different brain areas. Based on these activity patterns, the functional connectivity of the EEG data can also describe the inter relationship among the different brain areas of intertemporal choice decision.

(32) Choice behavior in dynamic Random-Interval Random-Ratio schedules of reinforcement

Author(s): Villarreal, Manuel; Velázquez, Carlos; Bouzas, Arturo (National Autonomous University of Mexico, Mexico). *Contact:* jesus_mvu@hotmail.com. *Abstract:* Organisms often have to make decisions in environments where reward contingencies change through time. After a change has occurred, an organism has to adapt its behavior to the new set of contingencies in order to maximize reward. Here we show data from an experiment where pigeons had to choose between concurrent schedules of reinforcement (Random Interval, Random Ratio), where, after 10 reinforcement deliveries, the value of the programs were selected at random and without replacement from 10 possible values within each session. We show that in the aggregate, pigeons have a strong preference for the Random Ratio schedule. This preference changed as a function of reinforcement and was reset to its original value after each of the 10 changes in the values of the programs. Additionally, the patterns of exploration and exploitation varied depending on the nature of the reward contingencies. For example, the amount of time that pigeons spend exploiting the Random Interval schedule was lower in comparison to the other program. Finally, we tested a set of computational models that aim to predict pigeon's choice patterns in the last sessions of the experiment.

(33) Making a wiser crowd: benefits of individual metacognitive control over forecasting questions

Author(s): Steyvers, Mark; Bennett, Stephen (University of California, Irvine, United States of America). *Contact:* mark.steyvers@uci.edu. *Abstract:* The wisdom of the crowd refers to the finding that judgments aggregated over individuals are typically more accurate than the average individual's judgment. Here we examine the potential for improving crowd judgments by allowing individuals to choose which questions to respond to. In circumstances where individuals' metacognitive assessments of what they know tend to be accurate, allowing individuals to opt in to questions of interest or expertise has the potential to create a more informed knowledge base over which to aggregate. In several experiments and in real-world forecasting tournament, we demonstrate that crowds composed of self-selected judgments are more accurate than crowds composed of experimenter-selected questions. We also discuss new results related to a recent forecasting tournament where forecasters can not only choose which forecasting questions to respond to but also indicate whether the question is better handled by a human forecaster or a machine algorithm. The initial results show that forecasters have the metacognitive awareness to distinguish between forecasting questions for which human assistance leads to superior results. Overall, the results show that allowing individuals to use private metacognitive knowledge holds much promise in enhancing judgments, including those of the crowd.

(34) Counterintuitive Concepts Across Domains, A Unified Phenomenon?

Author(s): Sommer, Joseph; Smith, Jamel; Musolino, Julien; Hemmer, Pernille (Rutgers University, United States of America). *Contact:* joseph.sommer@rutgers.edu. *Abstract:* A leading hypothesis regarding the origin and formation of supernatural concepts is that they are a byproduct of more mundane cognitive structures and mechanisms. These concepts are hypothesized to be better remembered and transmitted because they are "minimally counterintuitive" (Boyer, 2001) (MCI), that is, they contain a small number of violations of ontological assumptions that make them salient. According to MCI theory, cultural transmission of counterintuitive concepts is aided by their ability to fit into a cognitive optimum for memory. MCI concepts are optimal because their small number of violations increases salience while only minimally complicating their inferential structure. However, the violation of expectations leading to improved recall is not unique to supernatural concepts. The von Restorff (VR) effect (1933) describes a pattern of increased memorability for outlier items presented in the context of an otherwise homogenous set. The two phenomena bear a striking similarity and may be manifestations of the same underlying cognitive mechanisms. Study 1 develops and norms a novel set of stimuli on dimensions known or theorized to be drivers of memorability, including Barrett's (2008) conceptualization of inferential potential, or a concept's ability to produce thoughts and predictions in a person's mind. Study 2 assesses memory to compare the MCI and VR effects and to determine whether the two are governed by the same underlying cognitive processes. Results and implications will be discussed.

(35) Evaluating the role of contingency and contiguity on the sense of agency

Author(s): Saad, Laura; DeLuna, Jesus; Rothrock, Jane; Musolino, Julien; Hemmer, Pernille (Rutgers University, United States of America). *Contact:* laura.saad@rutgers.edu. *Abstract:* The sense of agency (SoA) refers to the subjective experience of control over our actions and our environment. SoA can be measured both implicitly, via intentional binding, or explicitly, via self-report. Intentional binding (IB) refers to the subjective compression of the time interval between a voluntary action and its associated outcome. Studies have evaluated the effect of contiguity and contingency on intentional binding but it is still unclear the role each plays on the relationship between IB and explicit SoA. The primary goal of this study is to evaluate the impact of contiguity and contingency on IB and explicit SoA separately but also to elucidate the role they play on the relationship between these two processes. Contiguity will be manipulated by varying the timing interval between the action and the outcome. The role of contingency will be evaluated by varying the inter-trial intervals. Participants will be asked to report the subjective timings of actions or outcomes and to subsequently evaluate their explicit sense of agency by reporting their feelings of control across the different conditions. The results of this study will provide useful insights into the mechanisms that underlie both intentional binding and the explicit experience of control across different contexts. Implications and future research directions will be discussed.

(36) Comparative performance of item response models for anchoring vignettes data

Author(s): Hojo, Daiki[(1,2)]; Okada, Kensuke[(1)] (1: the University of Tokyo, Japan; 2: Japan Society for the Promotion of Science). *Contact:* dhojo@p.u-tokyo.ac.jp. *Abstract:* In the anchoring vignettes method, respondents are asked to rate items not only for themselves but also for hypothetical persons described in the vignettes. This can be useful in measuring and correcting for response style biases in psychological self-report questionnaires. Recently, several extended item response models based on the graded response and partial credit models have been proposed for anchoring vignettes data. However, their comparative performance with actual psychological questionnaire data has not been fully investigated. Therefore, the main objective in this study is to evaluate the comparative performance of these models for empirical data of self-report and vignette questionnaire items in which the measurement of conscientiousness is of primary interest. The models are compared in terms of their empirical parameter estimations, in-sample prediction performance,

and Bayes factors. Small differences are found among the results of posterior predictive checks. We further discuss the results and implications of the model comparison as well as the applicability of IRTrees and other cognitively based models.

(37) Dimensionality Reduction for Joint Modeling

Author(s): Halpern, David Jacob[(1)]; Tubridy, Shannon[(1)]; Davachi, Lila[(2)]; Gureckis, Todd[(1)] (1: New York University, United States of America; 2: Columbia University). *Contact:* david.halpern@nyu.edu. *Abstract:* Many cognitive processes of interest have either very sparse or no easily obtainable observable behavioral signals. Therefore, neuroimaging data such as signals from fMRI and EEG have great promise for estimating parameters and testing cognitive models. The recently developed joint modeling framework (Turner et al. 2013, 2015, 2016, Palestro et al. 2018) provides methods for fitting models simultaneously to neural and behavioral data, allowing us to infer which models and parameters most parsimoniously explain both sets of data. However, for both computational and theoretical reasons, it is often important to find some way to reduce the dimensionality of the neural data before relating it to cognitive models. The existing joint modeling literature provides relatively little guidance on what considerations are relevant when making decisions about dimensionality reduction and existing work uses a wide variety of approaches such as anatomically-derived regions of interest (ROIs) (e.g. Turner et al. 2016) and ICA (e.g. Turner et al. 2013). Here we investigate the sensitivity of joint modeling inferences in a recent memory experiment (Tubridy et al. 2018) to various choices of reduction methods including anatomically-derived ROIs, ICA and HTFA (Manning et al. 2017). We also discuss some possible directions for developing new cognitive model-based approaches to dimensionality reduction for joint modeling.

(38) Correlation-adjusted standard errors and confidence intervals for within-subject designs: A (much) simpler solution

Author(s): Cousineau, Denis (Université d'Ottawa, Canada). *Contact:* denis.cousineau@uottawa.ca. *Abstract:* In within-subject designs, the multiple scores of a given participant are correlated. This correlation implies that the observed variance can be partitioned into between-subject variance (which is of no theoretical interest) and between-measures variance (which is caused by the effect of interest). The basic confidence interval about the mean does not separate these two sources and is therefore of little use in within-subject designs. Two solutions have been proposed, requiring fairly complex computations (Loftus and Masson requires the computation of the subject ffı all within-subject factors' interaction's sum of square; Cousineau and Morey requires a two-step transformation of the data) even though the two are mathematically equivalent. Herein, we present a correlation-adjusted method which only requires the mean correlation across all pairs of measurements. This solution is shown to be exact for data satisfying the compound symmetry assumption and to be adequate for data satisfying the sphericity assumption. A formal test of compound symmetry is also discussed.

ICCM posters (Ballroom Center & East)

(39) Conceptually Plausible Bayesian Inference in Interval Timing *Author(s):* Sarah Caroline Maaß, Leendert van Maanen and Hedderik van Rijn.

(40) Kickstarting Adaptive Fact Learning Using Hierarchical Bayesian Modelling *Author(s):* Maarten van der Velde, Florian Sense, Jelmer Borst and Hedderik van Rijn.

(41) Predictions of a Model of Language Comprehension Compared to Brain Data *Author(s):* Peter Lindes.

(42) Are Standard Reinforcement Learning Models too Flexible? *Author(s):* Patrick Rice, Mathi Manavalan and Andrea Stocco.

(43) Testing a Complex Training Task *Author(s):* Frank E. Ritter, Farnaz Tehranchi, Mat Brener and Shan Wang.

(44) Automated cognitive modeling with Bayesian active model selection *Author(s):* Vishal Lall, Jordan Suchow, Gustavo Malkomes and Thomas Griffiths.

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