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New Measures for Fundamentals of Human Performance

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We bring together researchers who apply a variety of mathematical tools in their research on human performance. Travis Wiltshire examines the social interactions of team members. Chris Sims pushes forward the assessment of individuals via computational rationality. Rahman and Gray shine their Spotlight on the dips and leaps of performance during skill acquisition. Elizabeth Torres examines stochastic shifts in learning across the lifespan. We maintain that these lines of research show common ground and we have challenged each of our panelists to look for and highlight that common ground in their presentation.

Chris R. Sims – *Computational Rationality: A New Frontier in the Assessment of Individual Behavior*

Computational rationality is an emerging paradigm for understanding biological intelligence as efficient computing. In this symposium, we argue that computational rationality offers a new, and incisive tool for the assessment of individual behavior. Stated simply, people differ in computational resources such as working memory, attention, or motor ability and these differences in resources may translate into differences in both strategy and performance. We argue that such performance variation is neither arbitrary nor unpredictable but emerges from the definition of computational rationality as used in the formal analysis of behavior.

A long-understood constraint on biological intelligence is information theoretic channel capacity, which places strong limits on the ability to perceive, store, and process information. This limit was most famously demonstrated in Miller's (1956) paper, "The magical number seven, plus or minus two: Some limits on our capacity for processing information". While Miller defined the relevant limit, he left unanswered the question of what constitutes optimal behavior subject to this limit. Namely, given a finite constraint on the ability to store, transmit, or process information, what is the optimal performance achievable in a given task? And how does that compare to actual human performance? Using the framework of computational rationality, these questions have formal answers. In particular, a branch of information theory known as rate-distortion theory concerns the problem of optimizing utility subject to constraints on information processing. In recent years, the mathematics of rate-distortion theory have been applied to human information processing, in domains including visual working memory (Sims, Jacobs, & Knill, 2012; Sims 2015), absolute identification (Sims, 2016), and perceptual generalization (Sims, 2018). In each case, human performance can be quantified according to its computational efficiency – how well behavior achieves the standard of optimality defined relative to the particular information processing limitations of the individual. We argue that the most promising new frontier for this approach is turning it towards the exploration and explanation of individual differences in cognitive strategy, an argument which will be bolstered with computational simulations. Computational rationality, and rate-distortion theory more specifically, predict that optimal mental representations and algorithms are defined by the limitations of the individual, as well as the behavioral consequences of committing different kinds of errors in a specific task environment.

Travis J. Wiltshire – *Social Coordination Dynamics in Collaborative Interactions*

Social interactions are pervasive in human life. However, in some social interactions, particularly in collaborative contexts (e.g., teamwork), the effectiveness of those interactions can directly facilitate desirable/undesirable outcomes (e.g., successful team problem solving). Varying forms of intra- and inter-personal coordination in different modalities (e.g., behaviors, speech/language, and physiology) emerge in many interactions and these can function toward facilitating effective interaction processes and collaborative cognitive processes.

In this talk, I outline the social coordination dynamics approach to collaborative cognition by emphasizing different forms of coordination (e.g., synchrony, phase transitions) with some empirical examples. One study, examining collaborative problem solving using NASA's Moonbase Alpha task, shows how a sliding window entropy method applied to team communication sequences can detect transitions in collaborative processes and how this measure predicts task performance (Wiltshire et al., 2018).

However, during collaborative interactions, as in any dynamical system, patterns of coordination form and dissipate

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at different time scales and time points. Thus, we should move beyond quantifying aggregate measures of coordination for a given interaction by focusing on how the relative strength of coordination changes over the time course of an interaction. As an example of this, I review findings from a study using the Moonbase task focusing on movement coordination (i.e., synchrony). In this work, we have shown that movement coordination occurs during complex computer-mediated collaboration at certain time scales, that the overall amount of coordination at certain time scales as well as the pattern of change in coordination over time differentially relate to collaborative task performance (Wiltshire et al., 2019).

I will conclude this talk by advancing theoretical, methodological, and modeling directions for understanding the function of social coordination across contexts and detecting transitions in coordination such that coordination-based measures can be used to facilitate more effective collaborations.

E. B. Torres – *Stochastic Shifts in Learning Performance Across the Lifespan*

Working on the modeling of adaptive learning and neuromotor control of complex human movements alerted Torres to age-dependent shifts in the patterns of motor variability differentiating deliberate from spontaneous learning (DL vs SL). Specifically, her research involving a cross section of the population from 3-60 years of age uncovered a power law characterizing the stochastic fluctuations of the hand speed in route to the target, during pointing and decision-making motions. The log-log linear relation and maturational shifts along this line extended to more complex motions in sports and ballet, whenever the participants underwent typical neurodevelopment. However, the shifts in stochastic signatures failed to manifest in autistics. This phenotypic feature of the autistic nervous system's performance during DL motivated Torres to further explore possible ways to induce the signatures' shift in autistics towards typical levels. This led to the discovery that SL (through exploration evoking self-discovery, rather than instructing and pre-defining goals) was a more appropriate way to teach autistics.

The generation and coordination of bodily movements requires the solution of multiple computational problems that shift priority in a phylogenetically orderly way, as the nervous systems mature 1. Traditional approaches to learning consider averaged trajectories in adult systems that have already undergone maturation; but when one examines infants as they transition to more mature states 2, it becomes evident that the patterns of variability in the fluctuations of their motions shift over time 3. There is a dynamically changing probability landscape that a single probability distribution function cannot capture. As the fluctuations in motor output are also sensed through kinesthetic channels (kinesthetic reafference), these shifting PDF families are important to properly carry on our statistical analyses and computational modeling. As such, the characterization of motor signatures during learning across different ages is critical. Here we leverage the wearable sensors revolution and show how to measure naturalistic complex behaviors that are deliberate. We also show how to track spontaneous behaviors that are consequential to what we deliberately intent to do, as SL reflects the adaptive learning progression 4,5. We posit that it is the SL, occurring largely beneath awareness and scaping the naked eye that helps all systems (typically and atypically developing) learn to coordinate action and scaffold cognition, while resulting in a log-log linear relation, a.k.a. a power law of the deliberate ones.

Roussel Rahman & Wayne D. Gray – *Mining Data Hidden by Plateaus, Dips, and Leaps*

When plotted, the skill acquisition of individual learners often resembles a series of plateaus, dips, and leaps (PDL) (Gray & Lindstedt, 2017) more than it does the power-law of learning. Indeed, following Rickard's (2004) lead, we maintain that power law functions are endemic when the performance of many individuals is averaged together but rare when the performance of any single individual is examined.

Our recent research focuses on the routes which different individuals take to expertise. In this work, we analyzed nine individuals who each spent 31 hours playing 248 games of Space Fortress (SF). Across these games, for each individual, we can examine the many game scores and the performance measures for the plethora of skills required by the game. Using a measure of relative entropy as our *Spotlight*, we shine it on these scores and measures to reveal periods of individual discovery and change; indeed, such periods are revealed as dips and leaps in some, but not all, game measures and game scores.

Space Fortress is a complex game but to our surprise, as revealed by our Spotlight, most of our nine individual players show the same sequence of skill learning across their 31 hours of play. Indeed, it appears to us that most of these players recurrently employ a "design for the weakest link" principle to update their methods, with a caveat that the updates must also reinforce existing strengths of gameplay. For the weakest players some of these skills functioned as roadblocks; weaker players would advance so far in their skill development but hit some sort of perceptual, cognitive, action roadblock that precluded further advances. Hence, at the end of 31 hours and 248 games of play, the performance of several of our players remained stuck at stable suboptimal levels of performance; that is, rather than asymptoting, their performance plateaued (Gray, 2017).

Ray Perez – Basic Research for Complex Problems

Ray Perez has long pursued theory-based solutions to applied problems. He is co-organizer of this symposium as well as its moderator and discussant. In each of these three roles, Ray is focused on how complex tasks, sometime performed by a single person and other times performed by teams, are learned and executed.