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CONTENTS

Quantum cognition beyond Hilbert space II: Applications. Diederik Aerts, Lyneth Beltran, Massimiliano Sassoli de Bianchi, Sandro Sozzo and Tomas Veloz

Abstract: The research on human cognition has recently benefited from the use of the mathematical formalism of quantum theory in Hilbert space. However, cognitive situations exist which indicate that the Hilbert space structure, and the associated Born rule, would be insufficient to provide a satisfactory modeling of the collected data, so that one needs to go beyond Hilbert space. In Part I of this paper we follow this direction and present a general tension-reduction (GTR) model, in the ambit of an operational and realistic framework for human cognition [1]. In this Part II we apply this non-Hilbertian quantum-like model to faithfully reproduce the probabilities of the `Clinton/Gore' and `Rose/Jackson' experiments on question order effects. We also explain why the GTR-model is needed if one wants to deal, in a fully consistent way, with response replicability and unpacking eects.

Categorical Compositional Cognition. Yaared Al-Mehairi, Bob Coecke and Martha Lewis

Abstract: We accommodate the Integrated Connectionist/Symbolic Architecture (ICS) of Smolensky and Legendre (2006) within the categorical compositional semantics (CatCo) of Coecke et al. (2010), forming a model of categorical compositional cognition (CatCog). This resolves intrinsic problems with ICS such as the fact that representations inhabit an unbounded space and that sentences with differing tree structures cannot be directly compared. We do so in a way that makes the most of the grammatical structure available, in contrast to strategies like circular convolution. Using the CatCo model also allows us to make use of tools developed for CatCo such as the representation of ambiguity and logical reasoning via density matrices, structural meanings for words such as relative pronouns, and addressing over- and under-extension, all of which are present in cognitive processes. Moreover the CatCog framework is sufficiently flexible to allow for entirely different representations of meaning, such as conceptual spaces. Interestingly, since the CatCo model was largely inspired by categorical quantum mechanics, so is CatCog.

Testing boundaries of applicability of quantum probabilistic formalism to modeling of cognition: metaphors of two and three slit experiments. Irina Basieva and Andrei Khrennikov

Abstract: Analogy between the two slit experiment in quantum mechanics (QM) and the disjunction effect in psychology led to fruitful applications of the mathematical formalism of quantum probability to cognitive psychology. These quantum-like studies demonstrated that quantum probability (QP) matches better with the experimental statistical data than classical probability (CP). Similar conclusion can be derived from comparing QP and CP models for a variety of other cognitive-psychological effects, e.g., the order effect. However, one may wonder whether QP covers completely cognitive-

psychological phenomena or cognition exhibits even more exotic probabilistic features and we have to use probabilistic models with even higher degree of nonclassicality than quantum probability. It is surprising that already a cognitive analog of the triple slit experiment in QM can be used to check this problem.

Toward a Gauge Theory of Musical Forces. Peter Beim Graben and Reinhard Blutner

Abstract: How well does a given pitch fit into a tonal scale or key, being either a major or minor key? This question addresses the well-known phenomenon of tonal attraction in music psychology. Metaphorically, tonal attraction is often described in terms of attracting and repelling forces that are exerted upon a probe tone of a scale. In modern physics, forces are related to gauge fields expressing fundamental symmetries of a theory. In this study we address the intriguing relationship between musical symmetries and gauge forces in the framework of quantum cognition.

Probabilistic programs: Contextuality and relational database theory. Peter Bruza

Abstract: [4] have introduced a contextual probability theory called Contextuality-by-Default (C-b-D) which is based on three principles. The first of these principles states that each random variable should be automatically labeled by all condition under which it is recorded. The aim of this article is to relate this principle to block structured computer programming languages where variables are declared local to a construct called a ''scope''. In this way a variable declared in two scopes can be safely overloaded meaning that they can have the same label but pre- serve two distinct identities without the need for the modeller to label each variable in each condition as advocated by C-b-D. A core issue ad- dressed is how to construct a single probabilistic model from the various interim probability distributions returned by each syntactic scope. For this purpose, a probabilistic variant of the natural join operator of relational algebra is used to ''stitch'' together interim distributions into a single distribution. The semantics of this join operator are related to contextuality as discussed by [4] and [1].

An Introduction to Symmetric Inflated Probabilities. Mark Burgin

Abstract: Traditionally probability is treated as a function that takes values in the interval [0, 1]. All conventional interpretations of probability support this assumption, while all popular formal descriptions, e.g., axioms for probability, such as Kolmogorov's axioms, canonize this premise. However, researchers found that negative, as well as larger than 1 probabilities could be a useful tool in physics. Some even assert that probabilities that can be negative, larger than 1 or less than -1 are necessary for physics. Here we develop an axiomatic system for such probabilities, which are called symmetric inflated probabilities, and study their properties.

Exploration of Contextuality in a Psychophysical Double-Detection Experiment. Victor Cervantes and Ehtibar Dzhafarov

Abstract: The Contextuality-by-Default (CbD) theory allows one to separate contextuality from context-dependent errors and violations of selective influences (aka "no-signaling" or "no-disturbance" principles). This makes the theory especially applicable to behavioral systems, where violations of selective influences are ubiquitous. For cyclic systems with binary random variables, CbD provides necessary and sufficient condi- tions for noncontextuality, and these conditions are known to be breached in certain quantum systems. We apply the theory of cyclic systems to a psychophysical double-detection experiment, in which observers were asked to determine presence or absence of a signal property in each of two simultaneously presented stimuli. The results, as in all other behavioral and social systems previous analyzed, indicate lack of contextuality. The role of context in double-detection is confined to lack of selectiveness: the distribution of responses to one of the stimuli is influenced by the state of the other stimulus.

Graded Vector Representations of Immunoglobulins Produced in Response to West Nile Virus. Trevor Cohen, Dominic Widdows, Jason A. Vander Heiden, Namita T. Gupta and Steven H. Kleinstein

Abstract: Semantic vector models are used to generate high-dimensional vector representations of words from their occurrence statistics across large corpora of electronic text. In these models, the occurrence of a word or number in a particular context is treated as a discrete event, including numerical measurements of continuous properties. In addition, the sequence in which words occur is often ignored. In earlier work we have developed approaches to address these limitations, using graded demarcator vectors to represent measured distances in high-dimensional space. This permits incorporation of continuous properties, such as the position of a character within a term or a year of birth, into semantic vector models. In the current paper we extend this work by developing a novel representational approach for protein sequences, in which both the positions and the properties of the amino acid components of protein sequences are represented using graded vectors. Evaluation on a set of around 100,000 immunoglobulin receptor sequences derived from subjects recently infected with West Nile Virus (WNV) suggests that encoding positions and properties using graded vectors in- creases the similarity between immunoglobulin receptor sequences produced by cells from ancestral lines known to have developed in response to WNV, relative to those from other cell lines.

Contextuality in the Integrated Information Theory. J. Acacio de Barros, Carlos Montemayor and Leonardo Guimarães De Assis

Abstract: Integrated Information Theory (IIT) is one of the most influential theories of consciousness, mainly due to its claim of mathematically formalizing consciousness in a measurable way. However, the theory, as it is formulated, does not account for contextual observations that are crucial for

understanding consciousness. Here we put forth three possible difficulties for its current version, which could be interpreted as a trilemma. Either consciousness is contextual or not. If contextual, either IIT needs revisions to its axioms to include contextuality, or it is inconsistent. If consciousness is not contextual, then IIT faces an empirical challenge. Therefore, we argue that IIT in its current version is inadequate.

Is Stress Quantum-Like? J. Acacio de Barros, Leonardo Guimarães De Assis and Petr Bob

Abstract: Abstract. In this paper we examine two well-controlled experiments where order effects were shown under stress. We show that for such experiments the QQ equality of Wang and Busemeyer seems to be fairly satisfied for both experiments. Since one of the experiments measures physiological variables, this suggests that quantum order effect models have applicability outside of human judgment.

A first attempt at ordinal projective measurement. Jacob Denolf

Abstract: To our knowledge, all applications of the quantum framework in social sciences are used to model measurements done on a discrete nominal scale. However, especially in cognition, experiments often produce data on an ordinal scale, which implies some internal structure between the possible outcomes. Since there are no ordinal scales in Physics, orthodox projection-valued measurement (PVM) lacks the tools and methods to deal with these ordinal scales. Here, we sketch out an attempt to incorporate the ordinal structure of outcomes into the subspaces representing these outcomes. This will also allow us to reduce the dimensionality of the resulting Hilbert spaces, as these often become too high in more complex quantum-like models. To do so, we loosen restrictions placed upon the PVM (and even POVM) framework. We discuss the two major consequences of this generalization: scaling and the loss of repeatability. We also present two applications of this approach, one in game theory and one concerning Likert scales.

Eigenlogic: a Quantum View for Multiple-Valued and Fuzzy Systems. François Dubois and Zeno Toffano

Abstract: We propose a matrix model for two- and many-valued logic using families of observables in Hilbert space, the eigenvalues give the truth values of logical propositions where the atomic input proposition cases are represented by the respective eigenvectors. For binary logic using the truth values {O,1} logical observables are pairwise commuting projectors. For the truth values {+1,-1} the operator system is formally equivalent to that of a composite spin 1/2 system, the logical observables being isometries belonging to the Pauli group. Also in this approach Fuzzy logic arises naturally when considering non-eigenvectors. The fuzzy membership function is obtained by the quantum mean value of the logical projector observable and turns out to be a probability measure in agreement with recent quantum cognition models. The analogy of many-valued logic with quantum angular

momentum is then established. Logical observables for three-value logic are formulated as functions of the *Lz* observable of the orbital angular momentum l=1. The represntatitve 3-valued 2-argument logical observables for the Min and Max connectives are explicitly obtained.

A New Perspective on Observables in the Category of Relations: a Spectral Presheaf for Relations. Kevin Dunne

Abstract: The category of finite sets and relations FRel is studied extensively in categorical quantum mechanics as it shares much of the important categorical structure of the category of finite dimensional Hilbert spaces. In this paper look at FRel from the perspective of the topos approach to quantum theory by considering commutative subsemirings of hom sets FRel(A,A). In particular we define a functor analogous to the spectral presheaf of Doering and Isham and give a structure theorem for these semirings. We then relate this construction to dagger-SCFAs in FRel.

Contextuality-by-Default 2.0: Systems with Binary Random Variables. Ehtibar Dzhafarov and Janne Kujala

Abstract: The paper outlines a new development in the Contextuality- by-Default theory as applied to finite systems of binary random variables. The logic and principles of the original theory remain unchanged, but the definition of contextuality of a system of random variables is now based on multimaximal rather than maximal couplings of the variables that measure the same property in different contexts: a system is considered noncontextual if these couplings are compatible with the distributions of the random variables sharing contexts. A multimaximal coupling is one that is a maximal coupling of any subset of the random variables being coupled. Arguments are presented for why this modified theory is a superior generalization of the traditional understanding of contextuality in quantum mechanics. The modified theory coincides with the previous version in the important case of cyclic systems, which include the systems whose contextuality was most intensively studied in quantum physics and behavioral sciences.

Does Chomsky's 'Universal Grammar' for Language Derive from Quantum Pathways in Brain Microtubules? Stuart Hameroff

Abstract: 'Quantum-like' models of language suggest contextual, non-compositional emergence of meaning (1). Noam Chomsky has famously proposed that language has a structural basis ('universal grammar') embedded somewhere in brain biology, e.g. schematically represented by 'X-bar' branching patterns for words, phrases and sentences (3). However X-bar patterns have yet to be demonstrated in the brain (and neither have structural bases for memory, cognition and consciousness). Recently, meaning in both English and Chinese words, sentences and phrases was shown to be represented in hierarchical levels of EEG/MEG (up to ~100 Hz) (4). Origins of EEG/MEG remain unknown, but are suggested to occur as 'beat frequencies' of faster (e.g. megahertz) quantum vibrations in

microtubules inside neurons (5). In the Penrose-Hameroff model of 'orchestrated objective reduction' ('Orch OR'), quantum computations in brain microtubules mediate consciousness via quantum bits ('qubits') of vibrational pathways through skewed microtubule hexagonal lattices following the Fibonacci sequence. This results in X-bar branching patterns which intersect and interfere on cylindrical microtubule lattices, capturing basic elements of an unbound computational system in a finite space (in which memory, by CaMKII phosphorylation (6) may also be encoded). Quantum states in microtubules appear to derive from terahertz pi resonance dipole oscillations among aromatic amino acid rings, part of a hierarchy of vibrational resonances in terahertz, gigahertz, megahertz, kilohertz and hertz (EEG/MEG frequencies) observed in microtubules (7-11). Chomsky's 'universal grammar' (specifically his 'third factor' of language, neither encoded in the genome, nor learned from the environment) may derive from quantum computations in the logic of X-bar Fibonacci pathways in brain microtubules. References: (1) Bruza (2011) Concept combination, emergence and abduction. Proceedings 2010 International Conference on Information Retrieval and Knowledge Management, 1-5, (2) Chomsky (2007). "Approaching UG from Below". In Studies in Generative Grammar. Berlin: Mouton de Gruyter. ISBN 978-3-11-018872-1., (3) Piattelli-Palmarini & Medeiros (2012) Steps towards the physics of language Colloquium talk: University of Arizona, (4) Ding et al (2015) Nature Neuroscience, (5) Hameroff & Penrose (2014) Phys. Life Rev., 11(1):39-78, http://www.sciencedirect.com/science/article/pii/S1571064513001188, (6) Craddock et al (2012) PLoS ONE. 7: e37351. (7) Sahu et al (2013) Biosens. Bioelectron. 47: 141-148. (8) Sahu et al (2013) Appl. Phys. Lett. 102: 123701. (9) Sahu et al (2014) Scientific Reports 4:7303-1 DOI:10.1038/srep07303, (10) Craddock et al (2014) J Roy Soc Interface 05/11(100). DOI:10.1098/rsif.2014.0677, (11) Craddock et al (2015) Curr Topics Med Chem 15 (6) 523-533(11)

On the interpretation of probabilities in generalized probabilistic models. Federico Holik, Sebastian Fortin, Gustavo Bosyk and Angelo Plastino
Abstract: We discuss generalized pobabilistic models for which states not necessarily obey Kolmogorov's axioms of probability. We study the relationship between properties and probabilistic measures in this setting, and explore some possible interpretations of these measures.

Language Geometry using Random Indexing. Aditya Joshi, Johan Halseth and Pentti Kanerva
Abstract: Random Indexing is a simple implementation of Random Projections with a wide range of applications. It can solve a variety of problems with good accuracy without introducing much complexity. Here we demonstrate its use for identifying the language of text samples, based on a novel method of encoding letter N-grams into high-dimensional Language Vectors. Further, we show that the method is easily implemented and requires little

computational power and space. As proof of the method's statistical validity, we show its success in a language-recognition task. On a difficult data set of 21,000 short sentences from 21 different languages, we achieve 97.4% accuracy, comparable to state-of-the-art methods.

Probabilistic Nature of a Field with Time as a Dynamical Variable. Hou Yau

Abstract: Taking time as a dynamical variable, we study a wave with 4-vector amplitude that has vibrations of matter in space and time. By analyzing its Hamiltonian density equation, we find that the system is quantized. It obeys the Klein-Gordon equation and thus also the Schrodinger equation. Only a probability can be assigned for the detection of a particle. This quantized field has physical structures that resemble a zero-spin quantum field.

Decision Fusion via Attribute Boostrap Aggregation in Quantum Machine Learning. David Windridge and Raja Nagarajan

Abstract: Quantum Machine Learning is a subset of Quantum Computing that was initiated by the demonstration of a quantum Support Vector Machine (SVM) by Rebentrost, Mohseni & Lloyd. The SVM constitutes perhaps the exemplar instance of a supervised binary classifier, i.e. an entity capable of learning an optimal discriminative decision hyperplane from labeled vectors $\{(\vec{x}, y) \mid \vec{x} \in \tilde{X},\ y \in \{-1, +1\}\}$ existing within a feature space. The standard SVM seeks to maximize the margin (i.e., the distance of the decision hyperplane to the nearest data point), subject to a constraint on the classification accuracy of the labelling induced by the hyperplane's delineation of a generalised decision boundary.

Bootstrap Aggregation (`Bagging') is a well established method within stochastic machine learning for removing variance from classifiers via the production of bootstrap ensembles to refine the final decision accuracy. It consists in randomly sampling, with replacement, d groups from the total set of training samples M, training the resulting classifiers and combining the output either via decision fusion (such as majority voting) or averaging in the case of regression-like classifiers.

Bagging can thus be considered a method for variance reduction (variance with respect to training-set permutation/sampling). It is therefore employed predominantly on classifiers tuned to favor reduction in bias rather than variance (bias in this sense being expected discrepancy from the Bayes optimal classifier). It may be shown that the most SVM-appropriate strategy for bootstrap aggregation, however, involves sampling of feature subspaces (referred to as either `attribute bagging' or the `random subspace method (RSM)').

We demonstrate that it is possible to implement quantum attribute bootstrap aggregation without computational penalty, harnessing the stabilizing characteristics of bagging without requiring additional logical gates. To do so,

we exploit quantum superposition in such a way as to guarantee that stochastic measurement of the output state will give rise to an aggregate (i.e. ensemble) decision without destroying the superposition over feature subsets induced within the SVM implementation. This is enabled by the linear decomposability of decision boundary parameters within the kernel-induced Mercer embedding space. The process is thus necessarily more economic in both execution time and the total number of logic gates required in comparison to classical (and even parallelized quantum) SVM implementations.

Testing Contextuality in Cyclic Psychophysical Systems of High Ranks.
Ru Zhang and Ehtibar Dzhafarov
Abstract: Contextuality-by-Default (CbD) is a mathematical framework for understanding the role of context in systems with deterministic inputs and random outputs. A necessary and sufficient condition for contextuality was derived for cyclic systems with binary outcomes. In quantum physics, the cyclic systems of ranks n= 5, 4, and 3 are known as systems of Klyachko-type, EPR-Bell-type, and Leggett-Garg-type, respectively. In earlier publications, we examined data collected in various behavioral and social scenarios, from polls of public opinion to our own experiments with psychophysical matching. No evidence of contextuality was found in these data sets. However, those studies were confined to cyclic systems of lower ranks ($n \leq 4$). In this paper, contextuality of higher ranks (n=6,8) was tested on our data with psychophysical matching, and again, no contextuality was found. This may indicate that many if not all of the seemingly contextual effects observed in behavioral sciences are merely violations of consistent connectedness (selectiveness of influences).

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