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Contextual models of Information Fusion

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14. ABSTRACT The core research objective of this project is to determine how observations with different types of associated uncertainty can be combined such that: 1. uncertainty is suitably assigned numerically to evidence 2. the level of trust in or reliance on a given data source or piece of data is adequately represented This project leveraged developments in the field of quantum information science in order to provide a principled theoretical framework and associated operational modelling language for determining "if" and then "how" combination of observations is possible. The key quantum concept being leveraged is contextuality. When decisions of trust are contextual, then a single joint probability distribution cannot be formed to model the decision making process. This impacts standard probabilistic models of information fusion which assume that the joint distribution can always be formed.			
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Contextual models of information fusion

07/16/2019

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Period of Performance: 07/11/2018 – 07/10/2019

Abstract: *Short summary of most important research results that explain why the work was done, what was accomplished, and how it pushed scientific frontiers or advanced the field. This summary will be used for archival purposes and will be added to a searchable DoD database.*

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1. uncertainty is suitably assigned numerically to evidence
2. the level of trust in or reliance on a given data source or piece of data is adequately represented

This project leveraged developments in the field of quantum information science in order to provide a principled theoretical framework and associated operational modelling language for determining “if” and then “how” combination of observations is possible. The key quantum concept being leveraged is contextuality. When decisions of trust are contextual, then a single joint probability distribution cannot be formed to model the decision making process. This impacts standard probabilistic models of information fusion which assume that the joint distribution can always be formed.

Introduction: *Include a summary of specific aims of the research and describe the importance and ultimate goal of the work.*

Research Aim 1 (Exploration): Diagnose and analyse the prevalence of contextuality in information fusion with regard to decisions of trust

Abstract from (Bruza & Fell, 2019):

This article documents an empirical pilot study conducted to determine whether decisions of image trustworthiness are contextual. Contextuality is an active area of investigation in quantum cognition, however there has been little compelling evidence of its presence in human information processing. A Bell scenario experimental design was employed which manipulated both content and representational features in order to minimize the difference in marginal probabilities across experimental conditions. In addition, participants were subjected to time pressure in order to promote more spontaneous decisions. Results revealed no significant differences in marginal probabilities, however, no evidence of contextuality was found. The study revealed a tension between the requirement for minimizing the difference in marginal probabilities and the need to produce the strong correlations required to empirically ascertain contextuality

Abstract from (Fell et al., 2019)

This study utilises an experiment famous in quantum physics, the Stern-Gerlach experiment, to inform the structure of an experimental protocol from which a quantum cognitive decision model can be developed. The 'quantumness' of this model is tested by computing a discrete quasi-probabilistic Wigner function. Based on theory from quantum physics, our hypothesis is that the Stern-Gerlach protocol will admit negative values in the Wigner function, thus signalling that the cognitive decision model is quantum. A crowdsourced experiment of two images was used to collect decisions around three questions related to image trustworthiness. The resultant data was used to instantiate the quantum model and compute the Wigner function. Negative values in the Wigner functions of both images were encountered, thus substantiating our hypothesis. Findings also revealed that the quantum cognitive model was a more accurate predictor of decisions when compared to predictions computed using Bayes' rule.

Research Aim 2 (Computational theory development): Develop quantum models of contextually sensitive information fusion and express them as probabilistic programs (P-programs)

Abstract from (Obeid et al., 2019):

This article explores how probabilistic programming can be used to simulate quantum correlations in an EPR experimental setting. Probabilistic programs are based on standard probability which cannot produce quantum correlations. In order to address this limitation, a hypergraph formalism was programmed which both expresses the measurement contexts of the EPR experimental design as well as associated constraints. Four contemporary open source probabilistic programming frameworks were used to simulate an EPR experiment in order to shed light on their relative effectiveness from both qualitative and quantitative dimensions. We found that all four probabilistic languages successfully simulated quantum correlations. Detailed analysis revealed that no language was clearly superior across all

dimensions, however, the comparison does highlight aspects that can be considered when using probabilistic programs to simulate experiments in quantum physics.

Abstract from (Bruza & Wittek, 2019)

This article presents a framework for analysing contextuality in human information processing. In the quantum cognition community there has been ongoing speculation that quantum-like contextuality may be present in human cognition. The framework aims to provide a convenient means of designing experiments and performing contextuality analysis in order to ascertain whether this speculation holds. Experimental designs are expressed as probabilistic programs. The semantics of a program are composed from hypergraphs called contextuality scenarios, which, in turn, are used to determine whether the cognitive phenomenon being studied is contextual. Examples are provided illustrate the framework as well as some reflection about its broader application to quantum physics.

Experiment: *Description of the experiment(s)/theory and equipment or analyses..*

See (Bruza & Fell, 2019, Fell et al., 2019)

Results, Discussion, Plans for Next Option Period: *Describe significant experimental and/or theoretical research advances or findings and their significance to the field. Describe the main objectives for the next year.*

See (Bruza & Wittek, 2019, Obeid et al., 2019) for descriptions of descriptions of theoretical advances and (Bruza & Fell, 2019, Fell et al., 2019) for experimental findings.

Objectives for 07/11/2019 – 07/10/2020 according to each research aim:

Research Aim 1 (Exploration): Diagnose and analyse the prevalence of contextuality in information fusion with regard to decisions of trust

1. Develop new experimental protocol(s) to investigate contextuality of decisions of image trustworthiness based on the cognitive analogue of the Stern-Gerlach device (Fell et al., 2019)(Researchers: Fell, Bruza, Dehdashti, Moreira)
2. Investigate contextuality in human decision making by means of bi-stable probabilistic models (Researchers: Bruza, Busemeyer, Moreira, Dehdashti)

Research Aim 2 (Computational theory development): Develop quantum models of contextually sensitive information fusion and express them as probabilistic programs (P-programs)

1. Develop a variant of quantum game theory based on bistable probabilities which allow the modelling of irrational decisions in game theory. Implement both classic and quantum variants of such games as probabilistic programs using the probabilistic programming language (PPL) computational framework being implemented in the project. Determine theoretical means to establish contextuality in bi-stable quantum games. Verify the presence of contextuality by means of simulations (Researchers: Obeid, Dehdashti, Bruza, Moreira, Fell)

2. Extend the PPL computational framework to allow Quantum Bayesian Networks (QBNs) to be specified as probabilistic program. Test the QBNs on realistic decision examples. (Researchers: Obeid, Moreira, Bruza, Dehdashti).

List of Publications and any Significant Collaborations that resulted from your AOARD supported project: *In standard format showing authors, title, journal, issue, pages, and date, for each category list the following:*

a) *papers published in peer-reviewed journals,*

Obeid, A. Bruza, P.D. & Wittek, P. (2019) Evaluating probabilistic programming languages for simulating quantum correlations, PLoS ONE, 14(1)

<https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0208555>

b) *papers published in peer-reviewed conference proceedings,*

Bruza, P.D & P. Wittek, P. (2019) Probabilistic programs for investigating contextuality in human information processing. Proceedings of the 11th International Conference on Quantum Interaction (QI 2018), LNCS, Springer.

Bruza, P.D. & Fell, L. (2019) Are decisions of image trustworthiness contextual? A pilot study. Proceedings of the 11th International Conference on Quantum Interaction (QI 2018), LNCS, Springer.

Fell, L., Dehdashti, S., Bruza, P.D. & Moreira, C. (2019) An Experimental Protocol to Derive and Validate a Quantum Model of Decision-Making. Proceedings of the 41st Annual Meeting of the Cognitive Science Society (CogSci 2019).

c) *papers published in non-peer-reviewed journals and conference proceedings,*

d) *conference presentations without papers,*

Bruza, P.D. Quantum models of image trustworthiness. Presented at Quantum Information Revolution: Impact to Foundations conference, Linnaeus University, Växjö, Sweden, June 10-13, 2019.

e) *manuscripts submitted but not yet published, and*

f) provide a list any interactions with industry or with Air Force Research Laboratory scientists or significant collaborations that resulted from this work.

Attachments: Publications a), b) and c) listed above if possible.

Important Note: If the work has been adequately described in refereed publications, submit an abstract as described above and refer the reader to your above List of Publications for details. If a full report needs to be written, then submission of a final report that is very similar to a full length journal article will be sufficient in most cases. This document may be as long or as short as needed to give a fair account of the work performed during the period of performance. There will be variations depending on the scope of the work.