

# Quantum Probabilistic Models Using Feynman Diagram Rules for Better Understanding the Information Diffusion Dynamics in Online Social Networks

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## Abstract

This doctoral consortium presents an overview of my anticipated PhD dissertation which focuses on employing quantum Bayesian networks for social learning. The project, mainly, aims to expand the use of current quantum probabilistic models in human decision-making from two agents to multi-agent systems. First, I cultivate the classical Bayesian networks which are used to understand information diffusion through human interaction on online social networks (OSNs) by taking into account the relevance of multitude of social, psychological, behavioral and cognitive factors influencing the process of information transmission. Since quantum like models require quantum probability amplitudes, the complexity will be exponentially increased with increasing uncertainty in the complex system. Therefore, the research will be followed by a study on optimization of heuristics. Here, I suggest to use an belief entropy based heuristic approach. This research is an interdisciplinary research which is related with the branches of complex systems, quantum physics, network science, information theory, cognitive science and mathematics. Therefore, findings can contribute significantly to the areas related mainly with social learning behavior of people, and also to the aforementioned branches of complex systems. In addition, understanding the interactions in complex systems might be more viable via the findings of this research since probabilistic approaches are not only used for predictive purposes but also for explanatory aims.

## Introduction

Humans are complex creatures. What makes them so complex is the difficulty in understanding and predicting their behaviour. Pioneering neoclassical economic thought assumed that individuals act with perfect rationality, and their decision-making process can be represented by utility functions. Although the well-known Expected Utility (EU) theory of von Neumann and Morgenstern (Von Neumann, Morgenstern, and Kuhn 2007) is accepted as the one of the most significant axiom in explaining human decision-making, Allais' paradox (Allais 1953) showed the complexity of human behavior under uncertainty; since the notion of perfect

rationality of individuals is an over-simplification of more complex phenomena. EU theorem, therefore, is improved to become the Subjective Expected Utility (SEU) theorem by pairing utility and probability functions to represent agents' desires and beliefs, respectively, by Leonard Savage and Richard Jeffrey (Savage 1972). Nevertheless, cognitive psychologists Amos Tversky and Daniel Kahneman's experiments (Tversky and Kahneman 1974) demonstrated the insufficiency of SEU theorem either in explaining the complexity of human decision-making. All these open questions regarding the complexity of decision-making remained relevant for years, and work of of Aerts & Aerts pioneered the field of Quantum Cognition by showing the necessity of a form of statistics between quantum and classical probability (Aerts and Aerts 1995).

Quantum cognition is a research area in which quantum mechanics foundations are integrated into the mathematical principles used in cognitive science. For years, unobserved cognitive biases which are known to have strong effects on individuals' decisions and actions, are represented by probabilistic models using latent variables; however, these models are highly complex and latent variables are not sufficient in explaining the causality relations of observed / unobserved effects and the behavior. Recent research shows that quantum probabilistic models yield better results in explaining complex behavior which cannot be easily explained by the pure classical models. The superiority of these models are shown in the cases which violate Prisoner's Dilemma (Wang et al. 2013), or even in biological interactions of cells (Asano et al. 2013)

## Problem Statement and Research Questions

Modeling information diffusion and opinion dynamics is challenging due to complex non-trivial individual and emergent collective human behavior in receiving, processing, and disseminating information. Quantum probabilistic models seems to be a good candidate for commonly used latent Bayesian network models, since those models abstract the causalities and give a more general representation; whereas, quantum like Bayesian networks can simulate both observed and unobserved effects in a single network (Moreira and Wichert 2018). However, there are some challenges in em-

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ploying these networks, which are scalability and complexity. The main purpose of this dissertation is to utilize these models into multi-agent systems rather than 2-agent systems, comparing different quantum models to find the best model and creating a new heuristic based on belief entropy to solve the complexity problem.

## Research Questions

- Recent research has shown the superiority of quantum like probabilistic models against pure classical models under uncertainty when two agents are present. Are these models applicable to the multi-agent systems to be further used in explaining human behaviour in a network?
- There are many quantum-like probabilistic models in which tuning of quantum parameters are manual (Khrennikov 2009), (Pothos and Busemeyer 2009); and automatic by using static heuristic (Yukalov and Sornette 2011) and dynamic heuristic (Moreira and Wichert 2014). Can heuristics based on entropy measures be an alternative to the extant heuristics in the literature?
- The variability of the information diffusion and opinion dynamics characteristics with changing network properties (assortativity, density, clustering, degree distribution etc.) is highly studied among researchers. Does the superiority of the quantum based probabilistic models over classical models vary with changing network properties?

## Proposed Method, Current and Anticipated Progress

This dissertation includes two phases. In Phase I, it is important to understand which cognitive biases might effect users' activities and preferences in OSNs (confirmation bias, hindsight bias, recency bias etc.). After creating the cognitive map, the second step would be defining the OSN related latent user preferences (topic sensitivity, interactions between users, activity types etc.). The research is currently at this stage. I first investigated effects of degree-distribution and mixing patterns of entities in complex networks on information sharing characteristics to understand the dependencies of the user latent variables and network variables in Bayesian network. After creating the Bayesian network by determining the variables (social media based, cognitive effects etc.) and their dependencies, I propose using Feynman Path Diagram rules for Bayesian networks. In Phase II, first, I am planning to compare Feynman rules-based quantum Bayesian networks with the current quantum like approaches for two agent systems. Then, I will try to improve these models into multi-agent systems. Since the complexity will exponentially increase in such systems, I propose to use belief entropy based heuristics. Although static and dynamic heuristics methods work well, they struggle to bring a physical explanation to the situations of violated Sure Things Principle. A belief entropy based heuristics can be used by using belief uncertainty as an interference effect. Then I will conclude the study by proving the efficiency of belief entropy based heuristics compared to other dynamic heuristics used in Bayesian networks in the literature. The comparison

will be based on the probability of defect observed and that of computed by model as in literature.

## Potential Contributions and Future Directions

In this doctoral consortium, I propose the next generation of information diffusion research engaging knowledge and skills from multiple disciplines including network science, cognitive science, information theory, artificial intelligence and machine learning. The findings will be a significant improvement to the current information diffusion models. It is also important to understand the dependencies and variability of the current probabilistic models compared to quantum probabilistic models in understanding causal relationships in a complex network under uncertainty.

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