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Quantum Theory-Inspired Search☆

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Abstract

With the huge number and diversity of the users, the advertising products and services, the rapid growth of online multimedia resources, the context of information needs are even more broad and complex. Although research in search engine technology has led to various models over the past three decades, the investigation for effectively integrating the dimensions of context to deploy advanced search technology has been limited due to the lack of a unified modeling and evaluation framework. Quantum Theory (QT) has created new and unprecedented means for communicating and computing. Besides computer science, optics, electronics, physics, QT and search engine technology can be combined: interference in user interaction; entanglement in cognition; superposition in word meaning; non-classical probability in information ranking; complex vector spaces in multimedia search. This paper highlights our recent results on QT-inspired search engine technology.

Keywords: Information Retrieval; Quantum Probability Theory; Hilbert Vector Spaces; Language and Cognition

Scientific and Technological Challenge. Suppose a person is looking for information about Venice and types "venice". Such a word may mean "Serenissima Republic" (if he or she is a school child), "hostel" (if he or she is young person), "event" (if he or she is looking for a show). If the query is submitted by a traveller accompanied by a young child, it may mean two information needs - a father and his child wanting to go Venice may have incompatible aims. Thus, the specific information need strongly depends on the dimensions of context: user; task; place. One may suggest that the above problem can be solved by adding more words in the query. This does not always work because the user may not know which word to use, is interacting through an expensive mobile network, or has experienced that adding a new word did not work in the past. The key issue preventing the implementation of such scenarios is the lack of a unied theoretical framework.

Contribution. We aim at developing theories, methods and implementations to validate the hypothesis that Quantum Theory (QT) can inspire effective approaches to the new challenges posed to search engine theory and technology

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that traditional models, experimentation/evaluation protocols and conventional search technologies built upon them are insufficient to deal with.

In 2004, the IR seminal book [1] has shown that major search models (logical, probabilistic, vectorial) are subsumed by the single mathematical formalism provided by Hilbert spaces, thus suggesting the idea that QT can be used as a metaphor of search. Moreover, in the same year it was proven that the formalization of QT shows very strong connections with the mathematical basis of semantic space models [2]. Over the years, there has been increasing evidence on the existence of quantum-like structures in context, for example, in human cognition [3–7], word compounds and spaces [8], implicit feedback [9].

Methods and Results. We aim at verifying whether the observables in search are *entangled.* If there exists entanglement, the next question would be how quantum correlations can be quantified. [10,11] To this end, we investigate entanglements between concepts in a semantic space provided by user search and interaction history in a personalized and collaborative search environment. [12,13] We study the combination of concepts using *superposition.* When humans access and retrieve information, they often make use of associations attributing new properties to combined concepts, which they would not consider applicable to the separate concepts. Thus, it is likely that non-classical concept combination forms the basis of human driven search. [14,15] This problem includes the *dimensionality reduction* due to the high dimensionality of a Hilbert space spanned by various contextual components, which make the decomposition and storage of vectors and density operators inefficient. [16,17] We address *interference* and *poly-representation* in interactive search. Incrementally extending search by e.g. adjusting parameters or slight modifications of models have not led to major improvement in retrieval performance. [18–22] *Visualization* in contextual search is also investigated within interaction. The problem is how to provide a visual description of the space of the user's information needs, how the information need evolves through time and interactions and how to graphically show user interactions and the context of the search within this space. [23] We investigate a complex Hilbert space model of text passages of documents with the goal to identify directly the quantum-like effects due to context on combinations of concepts. [24]

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