Towards Quantum-based DB+IR Processing based on the Principle of Polyrepresentation

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Abstract. The cognitively motivated principle of polyrepresentation still lacks a theoretical foundation in IR. In this work, we discuss two competing polyrepresentation frameworks that are based on quantum theory. Both approaches support different aspects of polyrepresentation, where one is focused on the geometric properties of quantum theory while the other has a strong logical basis. We compare both approaches and outline how they can be combined to express further aspects of polyrepresentation.

1 Introduction

The core idea behind the principle of polyrepresentation of documents [2] is that a document is defined by different representations that can be combined to determine the cognitive overlap where it is assumed highly relevant documents are likely to be contained. Examples of different representations of the same document are user-given ratings, reviews and comments, the author-given textual content or non-textual features of a multimedia document.

Inspired by van Rijsbergen's idea of applying the mathematics behind quantum theory for IR, seamlessly combining geometry, probability theory and logics [5], recent frameworks have approached polyrepresentation from different viewpoints. While in [1] a geometric framework is proposed which has a probabilistic interpretation, [9] comes from the database domain and has a quantum logic-based background [6], which can also be interpreted probabilistically. These approaches are complementary in the sense that they focus on different aspects of polyrepresentation on the one hand, and in its viewpoint of the underlying theory (geometrical vs. logic-based) on the other hand, with geometry as their common mathematical ground. Our intention in this study is therefore to learn from both approaches and figure out the potential we can gain from combining them.

2 Quantum-based Frameworks for Polyrepresentation

Van Rijsbergen argues in his seminal work [5] in support of a quantum mechanic/ logic-based interpretation of IR. He outlines how probability theory, logic, and geometry relate in the context of quantum theory. In the following subsections, we will discuss two approaches which are based on these findings. Both approaches reflect different aspects of the principle of polyrepresentation.

2.1 The IQIR Framework

The motivation behind the IQIR framework (Interactive Quantum-based IR) is to provide means for (interactive) information retrieval on the ground of quantum mechanics [1]. The framework is based on the assumption that there is an information need (IN) space, which is a real-valued Hilbert space. The user's IN is represented by a set of unit state vectors, reflecting the uncertainty the system has about the user's IN. The event that a document is relevant is modelled as a subspace. The probability of relevance is now determined by the squared length of the projections of the vectors onto the document subspace. To support polyrepresentation, a separate Hilbert space for each document representation is created. To determine the cognitive overlap, the single representation spaces and their state vectors are combined using the tensor product, which establishes a polyrepresentation space. Geometric means are provided to weight single representations according to their importance to the user and to control the cognitive overlap. Within the polyrepresentation space, a non-separable (or entangled) state expresses dependencies between document representations from the user's point of view. Another inherent feature of the framework is that the vectors representing the user's IN can dynamically be transformed to reflect several forms of user interaction and information need drifts. This is motivated by the fact that information needs are indeed dynamic by nature [2].

2.2 CQQL

In contrast to the aforementioned approach, the commuting quantum query language (CQQL) [6] models the IN as a subspace of a hypothetical real-valued Hilbert space on which documents, represented as vectors, will be projected in order to determine their probability of relevance. Again, polyrepresentation and the creation of the cognitive overlap is supported by combining the isolated Hilbert spaces, each describing the attributes of a single document representation, by means of the tensor product. Because of CQQL's background in DB theory, it differentiates between attribute values that will be modelled by orthogonal state vectors mirroring Boolean values and probability values that rely on non-orthogonal vectors. Although quantum logic itself does not form a Boolean algebra (because the law of distributivity is violated), the commuting projector describing the IN subspace is consistent with these rules. To guarantee this – generally speaking – CQQL restricts the query to not use more than one probability condition on one attribute, e.g, $title \approx$ "*polyrepresentation*" $\vee$ $title \approx$ "*quantum logic*". If this restriction is accepted, an IN can be modelled using the full structural power of a Boolean algebra, i.e, conjunctions, disjunctions, and negations. Note that this does not mean the re-introduction of the shortcomings of Boolean retrieval models such as unordered result sets or the absence of term weighting. Instead, CQQL fully supports weighted logical connectors in order to adjust a query according to the user's needs [8], i.e, to construct the cognitive overlap. Given a structured query that models the cognitive overlap expressing the user's IN, the relevance of all documents can be assessed.

3 Probabilities, Geometry and Logics for Polyrepresentation – Opportunities and Challenges

Because of their conceptual similarities, it is tempting to combine both approaches into one quantum-based DB and IR query model that supports the principle of polyrepresentation. Regarding a polyrepresentative query model, IQIR lacks the opportunity to express highly structured queries. Such queries relying on Boolean connectors are shown to support the polyrepresentation principle best [3]. CQQL offers means to incorporate such queries into the query model. An interesting result from the utilisation of quantum theory for IR in IQIR is the potential to introduce concepts like non-separable (entangled) states reflecting inter-relationships between parts of a query, the representation of the system's uncertainty about the user's IN and the possibility to reflect user interaction by means of quantum measurement. The first idea is not supported in CQQL so far. CQQL addresses the latter by a machine-based learning relevance feedback approach in order to adjust the present condition weights that eventually determine the cognitive overlap [7, 8].

Both approaches have in common that they rely on weights to steer the influence of different representations onto the cognitive overlap. IQIR offers so-called "don't care" aspects whereas CQQL equips all logical connectors with weights in order to personalise a query. Hence, both methods use – in a way – pseudo features to express different grades of importance for terms or parts of a query. A combination of both approaches would give us the possibility to create a framework that is able to reflect the system's uncertainty about the user's IN, react on IN drifts and represent interrelations between document representations, in combination with powerful querying mechanisms provided by a query language that supports concepts from databases and IR. This way, complex and possibly interactive retrieval strategies, as structured queries to given knowledge base of polyrepresented documents combining factual and content-oriented aspects, are supported.

One of the biggest open challenges to achieve this goal is the dual way documents and information needs are represented in both frameworks. In IQIR, the unit vectors represent the user's IN and subspaces represent documents, whereas in CQQL, these vectors describe one representation of a document and the user state (the query) is reflected by a projector/subspace. In CQQL, the document is considered the dynamic part that is measured against the projector, which resembles the viewpoint taken in [4]. Although somewhat dual, there is no standard way to translate one view into the other. A solution may be to regard the set of unit vectors in IQIR as an average or a probability distribution of projectors in CQQL. This may impose some restrictions on how we can model these vectors; we may for a start just deal with the case that the user's IN is represented by one vector only. As both approaches rely on weights to incorporate the dynamics of the user's search goal and the weights in CQQL already affect the projector it seems appropriate to pursue this idea further.

4 Conclusion

In this study we analysed two polyrepresentation frameworks that are based on the mathematical formalism of quantum mechanics. We have shown that both approaches are complementary when it comes to polyrepresentation, with geometry as common mathematical grounds. A combination of both approaches would lead to a powerful theoretical and also practical framework for polyrepresentation, giving rise to supporting complex retrieval strategies. One of the biggest challenges is the dual nature of both approaches, which we are going to address in our future work.

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References

1. Frommholz, I., Larsen, B., Piwowarski, B., Lalmas, M., Ingwersen, P., van Rijsbergen, K.: Supporting Polyrepresentation in a Quantum-inspired Geometrical Retrieval Framework. In: Proceedings of the 2010 Information Interaction in Context Symposium. pp. 115–124. ACM, New Brunswick (Aug 2010)
2. Ingwersen, P., Järvelin, K.: The Turn: Integration of Information Seeking and Retrieval in Context. Springer-11645 /Dig. Serial], Springer, Dordrecht (2005), http://dx.doi.org/10.1007/1-4020-3851-8/http://www.zentralblatt-math.org/zmath/en/search/?an=1079.68532
3. Larsen, B., Ingwersen, P., Kekäläinen, J.: The polyrepresentation continuum in IR. In: IIiX: Proceedings of the 1st international conference on Information interaction in context. pp. 88–96. ACM, New York, NY, USA (2006)
4. Melucci, M.: A basis for information retrieval in context. ACM Transactions on Information Systems (TOIS) 26(3) (2008), http://portal.acm.org/citation.cfm?id=1361687
5. van Rijsbergen, C.J.: The Geometry of Information Retrieval. Cambridge University Press, New York, NY, USA (2004)
6. Schmitt, I.: QQL : A DB&IR Query Language. The VLDB journal 17(1), 39–56 (2008), http://cat.inist.fr/?aModele=afficheN\&cpsidt=20038185
7. Zellhöfer, D.: Inductive User Preference Manipulation for Multimedia Retrieval. In: Böszörmenyi, L., Burdescu, D., Davies, P., Newell, D. (eds.) Proc. of the Second International Conference on Advances in Multimedia (2010)
8. Zellhöfer, D., Schmitt, I.: A Preference-based Approach for Interactive Weight Learning: Learning Weights within a Logic-Based Query Language. Distributed and Parallel Databases (2009), doi:10.1007/s10619-009-7049-4
9. Zellhöfer, D., Schmitt, I.: Approaching Multimedia retrieval from a Polyrepresentative Perspective. In: Proc. of the 8th International Workshop on Adaptive Multimedia Retrieval (to appear) (2010)