Report on the Quantum Information Access and Retrieval Theory Winter School

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Abstract

QUARTZ (Quantum Information Access and Retrieval Theory) is an Innovative Training Network that aims to educate its Early Stage Researchers to adopt a novel theoretically and empirically motivated approach to Information Access and Retrieval based on the quantum mechanical framework that gives up the notions of unimodal features and classical ranking models disconnected from context. The present document reports on the QUARTZ Winter School, one of the activities of the QUARTZ training programme. The school was held at the Department of Information Engineering of the University of Padova, Padova, Italy, from February 7 to February 14, 2018. This report describes the goal of the school framed within the training activities of the QUARTZ project, how the school was structured in terms of lectures and activities devoted to the acquisition of transversal skills.

1 Introduction

QUARTZ (Quantum Information Access and Retrieval Theory) is an Innovative Training Network (ITN) that aims to educate its Early Stage Researchers (ESRs) to adopt a novel theoretically and empirically motivated approach to Information Access and Retrieval (IAR) based on the quantum mechanical framework that gives up the notions of unimodal features and classical ranking models disconnected from context. [1] The objective of ITNs is to "raise excellence and structure research and doctoral training in Europe, extending the traditional academic research training setting, incorporating elements of Open Science and equipping researchers with the right combination of research-related and transferable competences." [2] In ITNs, joint research training and/or doctoral programmes are implemented by partnerships of actors from different countries across Europe and beyond — examples of actors are universities, research institutions, and businesses. The QUARTZ project involves seven organizations: University of Padova (Italy), The Open University (UK), University of Bedfordshire (UK), Vrije Universiteit Brussel (Belgium), University of Copenhagen (Denmark), Brandenburg University of Technology Cottbus-Senftenberg (Germany), and Linnæus University (Sweden). QUARTZ consists of thirteen individual ESR projects.

The QUARTZ training activities aim at helping the ESRs to achieve the best scientific and technological preparation in IAR and the quantum mechanical framework, international relationships with leading research groups in Europe and outside Europe, transversal skills useful to disseminate their own research work at the highest level possible, and to get a

deep understanding of the strategic priority of "Open Science" [3]. The QUARTZ training activities aim at complementing the doctoral schools offered by the organizations.

The training programme of QUARTZ is organized in three main areas:

- training through research (e.g. supervision, workshops)
- training activities
- transversal skill training

The Winter School[1] was held at the Department of Information Engineering of the University of Padova (Italy) from February 7 to February 14, 2018; no activities were carried out during the weekend (February 10-11). Besides ESRs, the school welcomed two external participants.

The QUARTZ Winter School was intended to train the ESRs in the multidisciplinary and intersectoral areas of QUARTZ including abstract vector spaces, probability, logic, machine learning, audio-visual information processing, decision and cognition. Besides lectures on these topics, the school included training activities devoted to the acquisition of transversal skills, such as how to design a research video and practical hints on agile techniques for knowledge workers.

The first QUARTZ Workshop was held in conjunction with the school, on the afternoon of February 7. The goal of the workshop was to give the ESRs an environment for meeting the senior researchers of the participating organizations and for presenting themselves to the other colleagues of the network. The workshop consisted of the ESR's self-introduction.

2 Lectures

The QUARTZ Winter School included 15 invited lectures by speakers both from companies and academia. A short description of the lectures is provided below.

- **Introduction to Information Access and Retrieval** by Massimo Melucci, University of Padova, Italy.

  The lecture was focused on the introduction of the main IR concepts, IR models and Evaluation. The lecture introduced the IR problem and fundamental concepts such as information, data, query and relevance; the main concepts and components of an IR system were also introduced (e.g. term, posting, index). The lecture covered different retrieval models: boolean logic modelling, vector space-based models, probabilistic models and statistical language models. The final part of the lecture covered the topic of Evaluation in IR.

- **User Interaction and Modelling in Multimedia IR** by Haiming Liu, University of Bedfordshire, United Kingdom.

  This lecture started with the introduction of the problem of Multimedia Information Retrieval (MIR), discussing peculiar issues that differentiate MIR from text-based IR. It was then introduced how the users could be brought into the search loop, specifically how to exploit user interactions and how to model the user. As regards the former, the lecture covered how forms of user interactions could be adopted to support retrieval and to support design (e.g. user interfaces design). As regards the latter, frameworks for user modelling such as the information foraging theory were introduced.

[1] `http://www.quartz-itn.eu/training/winter-school`

- **Introduction to Machine Learning** by Roi Blanco, Amazon – Core Machine Learning, Spain.

  This lecture aimed at the introduction of the basic concepts of Machine Learning (ML) and of the role of ML in IR. The lecture started with the introduction of ML basics, the main components of ML algorithms and the main types of learning problems (supervised, semi-supervised, unsupervised, reinforcement learning). Several supervised ML algorithms were briefly introduced. Evaluation of ML algorithms and the problem of generalization were then discussed. The last part of the lecture was focused on ML for IR. Learning to Rank was introduced and different classes of loss functions (point-wise, pair-wise, list-wise) used in IR were presented. The lectures ended with some recommendations for IR students when approaching ML techniques to address their research questions.

- **Research in video. Main guidelines to communicate scientific results with video** by Marco Toffanin, University of Padova, Italy.

  The goal of this lecture was to provide the students with the basics on how to make a video for research. The lecture introduced the three main steps that need to be carried out: pre-production (scriptwriting), production (shooting), and post-production (editing). As regards production, practical hints to avoid common mistakes were presented; examples were provided to show the effect of different choices in production. As regards post-production multimedia principles were introduced. The final part of the lecture covered also some issues related to copyright, provided some sources for creative commons contents, and a list of software that could be used for the post-production step.

- **Introduction to Quantum Information and its applications** by Giuseppe Vallone, University of Padova, Italy.

  In this lecture an introduction to Quantum Information was provided. The lecture started with the introduction of the basic concepts of Quantum Mechanics, e.g. the notion of state, the superposition principle, measurement and no-cloning theorem, and the uncertainty principle. The lectures then covered Quantum Key Distribution, protocols involving Entanglement (e.g. Quantum Teleportation) and Quantum Random Number Generators.

- **Empirical Foundations of Quantum Cognition** by Zheng Wang, The Ohio State University, United States.

  Quantum theory provides a unified and powerful explanation for a wide variety of paradoxes found in human cognition and decision research ranging from attitude, inference, causal reasoning, judgment and decision, to perception and memory. This lecture reviewed applications of quantum cognition where classical models fail, including (1) conjunction/disjunction errors that violate rules of classical probability, (2) question order effects that violate commutativity, (3) interference effects that violate the law of total probability, (4) context effects that violate joint probabilities (including violations of Bell type inequalities), (5) asymmetric similarity judgments and violations of Euclidean distance models. This lecture focused on this new theoretical and modeling approach to a wide variety of empirical cognitive phenomena using a unified, common set of theoretical principles.

- **Theoretical Foundations of Quantum Cognition** by Jerome Busemeyer, Indiana University, United States.

  Quantum cognition is a rapidly growing new approach to building computational models of cognition and decision. The cognitive revolution in the 1960s was based on classical computational logic; the connectionist and neural network movements in the 1970s were based on classical dynamical systems; the current Bayesian cognition movement is based on classical probability theory. These classical assumptions remain at the heart of all these theories, and they are so commonly and widely applied that we take them for granted. However, what are the critical but hidden assumptions upon which all traditional theories rely? In this lecture, it was reviewed how quantum theory provides a fundamentally different approach to logic, reasoning, probabilistic inference, and dynamical systems in cognition and decision research. For example, quantum logic does not follow the distributive axiom of Boolean logic; quantum probabilities do not obey the disjunctive axiom of Kolmogorov probability; quantum reasoning does not obey the principle of monotonic reasoning. It turns out that humans do not always obey these classical restrictions either and a lot of puzzling human behaviors are consistent with predictions based on quantum models. This lecture provided an exposition of the basic assumptions of classical versus quantum theories. These basic assumptions were examined, side-by-side, in a parallel and elementary manner.

- **Introduction to Information Retrieval and Quantum Mechanics** by Massimo Melucci, University of Padova, Italy.

  This lecture introduced Quantum Theory IR Models and Frameworks. The lecture started by explaining how Quantum Theory inspired IR, Quantum Probability, the notions of superposition, interference and incompatibility and how these notions are related to some IR concepts and issues. The Quantum Probability Ranking principle was then introduced. The lecture then covered how the mathematical construct of vector space basis can be used to model context and how the generalized view of probability rooted in the quantum mechanical framework can be adopted to compute the probability of context. The last part of the lecture discussed retrieval as a problem of context detection, specifically using quantum detection theory.

- **Quantum Logic** by Ingo Schmitt, Brandenburg University of Technology Cottbus-Senftenberg, Germany.

  This lecture provided an introduction to quantum logic. The talk started with a motivating example. After recalling some mathematical constructs like poset and lattice theory it was shown, that all projectors together with their operations intersection and convex hull of union form a specific lattice which is the basic of quantum logic. Quantum logic is different from Boolean algebra. Next, the negation was introduced. Important properties of the logic were identified and consequences in practical use were derived. It was shown that the projector lattice contains subsets of projectors which obey Boolean algebra laws. Finally, a weighting scheme of operands of logical operations was introduced.

- **Natural Language Processing and Computational Linguistics** by Toine Bogers, Aalborg University Copenhagen, Denmark.

  This lecture provided the students with an introduction to Natural Language Processing (NLP) as well as a more detailed look at two specific applications of NLP: vector

semantics and text classification. A definition of NLP was provided along with an introduction of the levels of linguistic analysis and the main sources for complexity of NLP. Then NLP applications and a generic architecture shared by most NLP tools were presented. The second part of the lecture was focused on vector semantics, providing the students with an introduction to distributional semantics, to the problem of measuring word similarity and to evaluation. The last part of the lecture was focused on Text Classification, particularly on the Nave Bayes classification method, on the evaluation of text classifiers, and on practical issues that should be addressed when working with classifiers.

- **Design and Evaluation of Machine Learning based Information Retrieval Systems** by Emanuele Di Buccio, University of Padova, Italy.

  The lecture started with a brief review on the use of Machine Learning technologies to train a ranking model. The lecture was focused on two uses: how to automatically tune free parameters of IR models, if any, and approaches to learn how to optimally combine features. A brief review of ad-hoc IR and a concise introduction to evaluation campaigns, test collections, and effectiveness measures were provided. Ranking functions with free parameters (e.g. BM25) were then introduced. The lecture then focused on the problem of the optimization of free parameters, the motivations for optimizing ranking functions, a methodology to perform optimization and possible strategies to find the most effective parameter setting. The problem of optimization of parameters was then discussed with regard to other IR tasks, e.g. relevance feedback. Some open source software libraries were briefly presented. The final part of the lecture was focused on Learning to Rank (LtR), specifically on a methodology for LtR and on the evaluation of LtR algorithms; some available test collections (e.g. LETOR datasets) and open source software libraries were presented.

- **Polyrepresentation in a Quantum-inspired Information Retrieval Framework** by Ingo Frommholz, University of Bedfordshire, United Kingdom.

  A recent development in information access and retrieval is the utilisation of the theory of quantum mechanics as an expressive integrated framework to capture a user's context and interaction with the system. In this lecture it was briefly introduced the fundamentals behind the proposed quantum-theoretical information access and retrieval framework. It was discussed how information needs and relevance can be expressed in the proposed interactive framework, neatly combining geometry and (quantum) probability theory. A further well-established cognitive principle in information retrieval is polyrepresentation (or multiple evidence). Polyrepresentation states that the relevance of a document with respect to different representations determines its overall relevance. It was discussed how this principle can be integrated into the proposed quantum-inspired framework.

- **From Cognition to Computer Science I: Quantum Models of Cognition** by Sandro Sozzo, University of Leicester, United Kingdom.

  Traditional approaches to cognitive psychology model human judgment and decision-making using set-theoretical structures. However, accumulating empirical findings reveal that these structures are generally unable to model concrete human decisions, which makes problematical the interpretation of several cognitive phenomena in terms of classical logic and probability, and massively influences the development of applied disciplines, such as linguistics and artificial intelligence. Meanwhile, growing research

indicates that quantum theory provides the conceptual and mathematical framework to deal with these classically problematical situations in cognition. In this lecture, it was firstly introduced the combination problem of concept theory, that is, the problem of coherently representing the combination of two (or more) concepts in terms of the representation of the component concepts. Then, it was shown that classical modelling approaches lead to paradoxical conclusions, illustrated, e.g., by over-/under-extension effects in membership judgments, Guppy effects and borderline contradictions. It was then presented a quantum-theoretic framework for conceptual categorization which allows to faithfully represent different sets of data on conjunctions, disjunctions and negations of two concepts, explaining, at the same time, the observed deviations from classicality in terms of genuine quantum effects. It was shown how the quantum-theoretic framework can be successfully applied to more complex cognitive situations, like conjunctive and disjunctive fallacies, and disjunction effects. It was then put forward an explanatory hypothesis on human reasoning, which enables us to reconcile a whole set of cognitive phenomena under a unitary, rather than fragmented, framework.

- **From Cognition to Computer Science II: A Quantum Model of the World Wide Web** by Massimiliano Sassoli de Bianchi, Brussels Free University, Belgium.

  In this lecture it was shown that the approach offers a fundamental strategy for modeling the meaning associated with collections of documental entities, taking the World Wide Web as a paradigmatic example. In doing so, it was emphasized the importance of distinguishing the Web, made of printed documents, from a more abstract meaning entity, called the Quantum Web, where the former is considered to be the collection of traces that can be left by the latter, in specific measurements, similarly to how a non-spatial quantum entity like an electron can leave localized traces of impact on a detection screen. The double-slit experiment was extensively used to illustrate the rationale of the proposed model, which is guided by how physicists constructed quantum theory to describe the behavior of the microscopic entities. It was emphasized that the superposition principle and the associated interference effects are not sufficient to model all experimental probabilistic data, like those obtained by counting the relative number of documents containing certain words and co-occurrences of words. For this, additional effects, like context effects, must also be taken into consideration.

- **Agile for knowledge workers: practical hints** by Marco Dussin and Ivano Masiero, Independent Consultants, Italy.

  This lecture consisted in two activities: the Marshmallow Design Challenge[2] and the Dot Game[3]. These two activities are a useful tool to present and to foster discussion on some concepts related design and productivity. The first activity was originally proposed by Peter Skillman and was designed in order to show the importance of learning by doing and of addressing a problem with multiple iterations building successive prototypes to fix. The Dot Game is a real-time simulation of an assembly line where three types of actors are involved: some workers, a tester, and a client. The game allows typical behavioral patterns of work group to be shown and some concepts to be understood by means of a direct involvement in the simulation – e.g. how people in front of a bottleneck are causing problems when adding more work, or that much work in progress adds waste and makes it harder to detect and fix problems. The activities

[2] https://www.youtube.com/watch?v=H0_yKBitO8M

[3] https://www.netobjectives.com/system/files/DotGame_vas11_0.pdf

were followed by a discussion among the participants and lead by the lecturers, whose objective was to make explicit some issues that emerge when working in groups and that should be addressed in order to increase both the productivity and the quality of the work.

3 Team Building Activity

The team building activity was designed in order to encourage the collaboration between the students by carrying out a small project. The task assigned to the students was to design a workshop related to the main topic of the QUARTZ project: Quantum Information Access and Retrieval Theory. The students were divided in three groups (the number of components of each group ranged from three to four); group members were selected in order to avoid the presence of students from the same organization in the same group. The task was presented to the students on the afternoon of February 8. When describing the task (design a workshop on quantum information access and retrieval) no specific guidelines were provided. The main reason for this choice was not to bias the students towards specific solutions, thus allowing them to propose solutions other than the mini-conference format. The only "requirement" was to design a workshop fostering high interaction among participants. Each group worked in a separated room in order to minimize the interaction among groups during the activity. Each group was asked to produce internal minutes at the end of each team building session.

The main issue that emerged in the first session dedicated to the team building activity was to define a more focused topic for the workshop: Quantum Information Access and Retrieval was perceived as too broad. An approach shared by the different groups was to start from their own expertise and the topic of their ESR project in order to identify crucial issues to be addressed or a shared interdisciplinary approach involving the quantum mechanical framework. When designing the team building activity, a too broad topic was selected on purpose in order to stimulate the discussion among the ESRs on the issues perceived as crucial in Quantum IAR Theory.

The team building activity was also carried out in the last of time-slot on Friday 9 and in the morning of February 14. On February 14 the groups were asked to produce a short presentation to discuss their proposal in front of the other groups and the school participants.

There were three very different proposals. The first group reported on a proposal for a Quantum IAR framework combining poly-representation, ontologies and multi-modal information retrieval. They worked on a paper proposal; working on a paper was a way to define a more specific topic on which a workshop could be focused. The second group proposed a workshop on Quantum Inspired Neural Networks for IR. They presented related works on the subject, discussed several open issues, and proposed a workshop based on a tutorial format; the last part of the proposed workshop included a hand on session to implement Quantum Inspired Neural Networks IR models. The third group proposed a workshop in the "mini-conference format", providing a complete proposal in terms of topics of interest, submission format, and keynote speakers; each member of the group was assigned to a specific role in the organization of the workshop.

After each presentation, there was a brief discussion on the proposal and suggestions were provided by the other participants.

The main objective of the activity was to give to the ESRs the opportunity to start working on a project or on a topic together, to provide them with a first venue to discuss

research questions that they perceive as crucial for the QUARTZ project and Quantum IAR Theory in general. The proposals, the general discussion, and the final atmosphere of collaboration suggested that the activity fostered interactions in the intended direction.

4 Conclusions

The QUARTZ Winter School was intended to train the ESRs in the multidisciplinary and intersectoral areas relevant to the QUARTZ project, which include abstract vector spaces, probability, logic, machine learning, audio-visual information processing, decision and cognition. This objective was successfully achieved through the high-quality lectures given by invited speakers both from companies and academia. Moreover, the school benefited from the level of interaction of the ESRs, that actively participated to the lectures. One of the objectives of the school was to provide the ESRs with a venue to discuss both with senior researchers and their peers research questions that they perceive as crucial. The active participation of the ESRs during the lectures, the interaction and the collaboration among ESRs during the transversal skills training activities and the work they carried out during the team build activity suggest that this objective was successfully achieved.

5 Acknowledgements

We would like to thank all lecturers and participants to QUARTZ Winter School who made the school a success through their valuable contributions. Special thanks go to the Department of Information Engineering of the University of Padova for hosting the school and for the logistic support.

The activities were carried out as part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 721321.

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