Preface of the Special Issue: International Symposium “Worlds of Entanglement” - Second Part

Diederik Aerts¹ · Massimiliano Sassoli de Bianchi^{1,2} · Sandro Sozzo³ · Tomas Veloz^{1,4}

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This special issue is the second outcome of the International Symposium “Worlds of Entanglement,” held at the Free University of Brussels (VUB), on September 29–30, 2017, which had a follow up at the Institute of Philosophy and Complexity Sciences (IFICC), in Santiago de Chile, on March 7–8, 2019. The event gathered more than 50 scholars from different disciplines, ranging from pure mathematics to visual arts, and from multiple regions of the world, including Argentina, Austria, Canada, Chile, France, Germany, Italy, Japan, Poland and the United States, to animate an interdisciplinary dialogue about fundamental issues of science and society.

‘Entanglement’ is a genuine quantum phenomenon, in the sense that it has no counterpart in classical physics. It was originally identified in quantum physics experiments by considering composite entities made up of two (or more) sub-entities which have interacted in the past but are now sufficiently distant from each other. If joint measurements are performed on the sub-entities when the composite entity is in an ‘entangled state’, then the sub-entities exhibit, despite their spatial separation, statistical correlations (expressed by the violation of ‘Bell inequalities’) which cannot be represented in the formalism of classical physics.

✉ Tomas Veloz
tveloz@gmail.com

Diederik Aerts
diraerts@vub.ac.be

Massimiliano Sassoli de Bianchi
msassoli@vub.ac.be

Sandro Sozzo
s831@leicester.ac.uk

¹ CLEA, Brussels Free University, Brussels, Belgium

² Laboratorio di Autoricerca di Base, Lugano, Switzerland

³ School of Business and Centre IQSCS, University of Leicester, Leicester, UK

⁴ Fundación para el Desarrollo Interdisciplinario de la Ciencia, la Tecnología y las Artes, Santiago, Chile

As a consequence of these correlations, the composite entity and its properties cannot be entirely described in terms of the sub-systems and their properties. One typically says that, when entanglement is present, the sub-entities show some kind of non-classical connections, losing their identity, whereas the only possible description is in terms of a ‘global state’ which encodes the properties of all the entangled sub-entities as a whole, as if forming a bigger interconnected single entity (see, e.g., Schrödinger (1935) and Horodecki et al. (2009) and references therein).

After stimulating a lively debate among the founding fathers of quantum theory about its deepest meaning, entanglement and its spectacular implications, e.g., non-separability and contextuality at-a-distance or nonlocality, is nowadays fully employed as a powerful resource in a variety of technological applications, which include quantum cryptography, quantum computation, quantum information tasks, and quantum metrology, to the point that the informational and structural possibilities of quantum systems have become the core of many of today’s technologies (Dowling and Milburn 2003; Gyongyosi and Imre 2019; Aerts et al. 2019; Wang et al. 2020).

More recently, a growing amount of research has been devoted to identify quantum-theoretic structures, including entanglement, in non-physical domains, such as cognition, biology, ecology, computer and social sciences (see, e.g., Aerts 2009; Khrennikov 2010; Busemeyer and Bruza 2012; Melucci 2015 and references therein). The reason for the appearance of quantum-theoretic structures in these domains, however, has not to be searched in that nature is fundamentally made up of quantum entities at the micro-level but, rather, in that the entities studied in these domains exhibit aspects, when they interact with each other and with an external context, which makes the mathematical formalism(s) of quantum theory more suited than more traditional classical formalisms to represent them, their properties, their states and state transformations, their measurements and measurement statistics.

In particular, it has become increasingly evident that empirical violations of Bell inequalities and therefore quantum and/or quantum-type entanglement are systematically present in human language (see, e.g., Aerts et al. 2019 and references therein) whenever individual concepts combine to form composed conceptual entities, because the former create, in the combination process, meaning connections which cannot be represented within classical probabilistic formalisms, whereas they allow a quantum representation in terms of ‘entangled states’ and ‘entangled measurements’.

The foundations, peculiarities and applications of the notion of entanglement, meant in the broad sense above, has been the main aim of the two symposia. In particular, the present special issue incorporates articles that correspond to lectures at the first or second symposia, as well as invited contributions from scholars that participated in the events and the subsequent discussions. These discussions have indeed fostered interesting collaborations and are now giving birth to new research projects in different parts of the world.

More precisely, this issue includes works covering various aspects of entanglement: foundational questions (Diederik Aerts, Massimiliano Sassoli de Bianchi, Sandro Sozzo, Tomas Veloz, Marek Czachor, Nayla Farouki and Philippe Grangier), its application to modeling (Sandro Sozzo), its relation to social science (Urban Kordeš, Ema Demšar, Norah Bowman, Kathryn Schaffer, Gabriela Barreto and Luk Van Langenhove), and application to Complex Systems (William Lawless). Videos of the lectures can be found at <https://www.youtube.com/channel/UCKaagmCRZ84qF7xiBF93yQw>.

Worlds of Entanglement’s symposia were the natural continuation of past events organized by the Center Leo Apostel for Interdisciplinary Studies, around interdisciplinary reflection, in particular the “Einstein meets Magritte” Conference (1995), and the “Times

of Entanglement” Symposium (2010), which brought together some of the world’s most renowned thinkers.

We hope to make this attractive “Worlds of Entanglement” initiatives further grow, organizing new interesting interdisciplinary meetings in a next coming future.

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Diederik Aerts is professor at the Vrije Universiteit Brussel (VUB) and founding director of the Leo Apostel Centre for Interdisciplinary Studies (CLEA). He is Editor-in-Chief of the international ISI and Springer Nature journal Foundations of Science (FOS) and a board member of the Worldviews group, founded by the philosopher Leo Apostel. He is president of the Centre for Quantum Social and Cognitive Science (IQSCS) at Leicester University (UK), and is a Fellow of the College of the International Institute for Advanced Studies in Systems Research and Cybernetics (IIAS). He was the scientific and artistic coordinator of the Einstein meets Magritte conference in 1995, where the world’s leading scientists and artists gathered to reflect about science, nature, human action and society. CLEA was invited and participated in the World-Exhibition in Shanghai in 2010, with a follow up of this conference entitled ‘Times of Entanglement’. Diederik Aerts started his research with a focus on the foundations of quantum physics and, during the last two decades, also on cognitive science. In this respect, he is considered a pioneer of the research domain called quantum cognition. Aerts received in 2020 the Prigogine Award for his work in quantum cognition.

Massimiliano Sassoli di Bianchi graduated in physics from the University of Lausanne (UNIL), Switzerland, in 1989. From 1990 to 1991, he was an Assistant in the Department of Theoretical Physics (DPT) of the University of Geneva (UNIGE). In 1992, he joined the Institute of Theoretical Physics (IPT) at the Federal Institute of Technology in Lausanne (EPFL), as a Ph.D. candidate. He received the Ph.D. degree in physics from EPFL in 1995. Since 1996, he has been working in the private sector and as an independent researcher. In 2016, he joined the Center Leo Apostel for Interdisciplinary Studies (CLEA), at the Vrije Universiteit Brussel (VUB), as a research fellow. He is also the director of the Laboratorio di Autoricerca di Base

(LAB), in Lugano, Switzerland, and the Editor of the Italian journal *AutoRicerca*. His research activities are focused on the foundations of physics, quantum cognition and consciousness studies. He has written essays, popular science books, children's stories, and published numerous research articles in international journals.

Sandro Sozzo is associate professor at the University of Leicester. His research interests mainly concern the development of a novel theoretical perspective for human judgment and decision-making, with relevant applications to computer and social sciences. He is author of more than 90 publications, organised international conferences, managed special issues as guest editor, and was invited to give lectures in UK (Oxford), US, Canada, EU and China. He is the director of the "Centre for Quantum Social and Cognitive Science" (IQSCS), the secretary of the "International Quantum Structures Association" and the managing editor of the Springer Nature journal "Foundations of Science". Currently, he is investigator in the consortium "QUARTZ", involving seven European universities, which has recently been funded for a Marie Curie Innovative Training Network.

Tomas Veloz graduated in physics (B.Sc. 2004), in mathematics (B.Sc. 2008), and computer science (M.Sc. 2010), at the University of Chile. He obtained a Ph.D. in interdisciplinary studies at the University of British Columbia, Canada (2016), did 1-year postdoc at the Centre Leo Apostel for Interdisciplinary Studies (CLEA), at the Vrije Universiteit Brussel (VUB, 2016), where still maintains affiliation as research fellow, did a 3-year postdoc at the Institute of Philosophy and Complexity Sciences (IFICC – Chile, 2017-2020), where he also worked as director of the systemics department, a half year postdoc at the Science for the life foundation in Chile, where he directed a COVID19 modeling team (2020), and is currently a postdoc at CLEA again, leading a research team on mathematical modeling of reaction networks. His research focuses in mathematical modeling of interdisciplinary processes, with emphasis in quantum models applied to cognitive situations and reaction network models for system-theoretic models in biology and social systems. He is author of more than 40 articles, has organized international conferences, managed special issues as guest editor, and was invited to give lectures in various countries in EU and South America, as well as to UK, USA, Canada, and China.