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| **Course title** | **Picturing quantum weirdness** |
| **School name and date** | Quantum vs classical, August 7th – August 11th and August 14th , August 16th – August 19th (10 days) 9.00 a.m. – 4 p.m. UTC +2 |
| **Teaching staff** | Dr John Selby, Dr hab. Ana Belen Sainz |
| **Forms of classes, the realization and number of hours** | |
| 1. **Forms of classes** | Lectures and problem-solving sessions. |
| 1. **The realization of activities** | In person and, if necessary, a small online component. |
| 1. **Number of hours** | 60 (40 hrs of lectures and 20 hrs of problem solving sessions) |
| **Suggested prerequisite knowledge** | |
| No prior knowledge is necessary. We welcome enthusiasm and an open mind to learn a new way of thinking about the deepest questions in modern physics that have been challenging us for more than a century. | |
| **Brief description of the course** | |
| During the first week of the course, the students will be given a broad overview of the field of quantum information theory. What is special about this, however, is the fact that it will be taught from an exciting new perspective, that is, via pictures! This means that there are no mathematical prerequisites for the course, and that all of the ideas can be presented in an intuitive, but still fully rigorous, way. This new way of thinking about quantum theory is not only useful as a pedagogical tool, but it is also being widely used in quantum research and in quantum industry (e.g., Google, IBM, Quantinuum, among others). In the second week we will use many of these pictorial ideas, but applied to a much more focused topic. Specifically, the students will be introduced to a modern perspective on how the nonclassicality of quantum theory can be understood as a resource. They will understand how to mathematically formalise the notion of a resource, and then how various quantum phenomena (such as the Nobel-Prize winning quantum “nonlocality”) can be formally understood as resources underpinning emerging quantum technologies. | |
| **Course contents** | |
| 1. Diagrammatic mathematics; zx-calculus and process theories.  2. Quantum phenomena from a diagrammatic perspective: entanglement, teleportation, uncertainty.  3. Quantum foundations from a diagrammatic perspective: non-classicality, Bell’s theorem, generalised contextuality. Foundational discussion on what this all means.  4. Quantum computation from a diagrammatic perspective: quantum circuits, measurement-based quantum computing, error correction, circuit optimisation, quantum algorithms with quantum advantage.  5. Quantum communication from a diagrammatic perspective: quantum key distribution.  6. Kinds of non-classical resources and phenomena.  7. Hilbert space from diagrams. Quantum theory: a geometric view underpinned by the diagrammatic language.  8. Resource theories: a diagrammatic process-theoretic approach.  9. Kinds of non-classical resources. Resource theories of non-classicality. Semidefinite programs and linear programs as resource-conversion tests. | |
| **Literature** | |
| 1. *Quantum in Pictures: A New Way to Understand the Quantum World*. B. Coecke and S. Gogioso. Cambridge Quantum. ISNB-10 1739214714. (2023)  2. *Picturing Quantum Processes: A First Course in Quantum Theory and Diagrammatic Reasoning*. B. Coecke and A. Kissinger. Cambridge University Press. DOI=10.1017/9781316219317. (2017).  3. *Kindergarden quantum mechanics graduates... or how I learned to stop gluing LEGO together and love the ZX-calculus*. B. Coecke, D. Horsman, A. Kissinger, Q. Wang. Theoretical Computer Science 897, 1 (2022).  4. *ZX-calculus for the working quantum computer scientist*. John van de Wetering. ArXiv:2012.13966 (2020).  5. *A mathematical theory of resources*. B. Coecke, T. Fritz, and R. W. Spekkens. Information and Computation 250, 59 (2016).  6. *Quantifying Bell: the Resource Theory of Nonclassicality of Common-Cause Boxes*. E. Wolfe, D. Schmid, A. B. Sainz, R. Kunjwal, and R. W. Spekkens. Quantum 4, 280 (2020).  7. *Quantifying EPR: the resource theory of nonclassicality of common-cause assemblages*. B. Zjawin, D. Schmid, M. J. Hoban, and A. B. Sainz. Quantum 7, 926 (2023). | |
| **Contact** | ana.sainz@ug.edu.pl |