Alessandro Tosini

Curriculum Vitae

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Personal information

sex: male
nationality: Italian
date and place of birth: 27^{th} June 1985, Brescia (IT)

Research Fields

Theoretical and mathematical aspects of Quantum Theory and Quantum Information.
Foundations of Quantum Theory and Quantum Field Theory

Academic Positions

February 2020 — French Qualification for Maître de conférences in the Section 28 "Milieux denses et matériaux" (N. 20228346574).

December 2019–present — **Research fellowship**, *Quantum information theory group, University of Pavia*, Italy.
Project: Complementarity, information and disturbance in operational probabilistic theories.

March 2019–August 2019 — **Research fellowship**, *Quantum information theory group, University of Pavia*, Italy.
Research Project: Operational theories.

2016–2019 — **Postdoctoral Researcher**, *Quantum information theory group, University of Pavia*, Italy.
Project: Quantum causal structures.

2013–2016 — **Postdoctoral Researcher**, *Quantum information theory group, University of Pavia*, Italy.
Project: Quantum cellular automata and informational approach to quantum field theory.

Education

2009–2013 — **PhD in Theoretical Physics**, *University of Pavia*, Italy.
Thesis title: A QUANTUM CELLULAR AUTOMATA FRAMEWORK FOR QUANTUM FIELDS DYNAMICS.
Supervisor: Prof. G. M. D'Ariano.
Thesis evaluated positively by the external referees Prof. Dr. G. Amelino Camelia and Prof. João Magueijo.

June 2011 — 11^{th} **Canadian Summer School on Quantum Information**, *Sherbrooke University*, Canada, Final exam evaluation: A+.

2007–2009 — **M.Sc. in Theoretical Physics**, *University of Pavia*, Italy, *110/110 cum laude*.
Thesis title: PROBABILISTIC THEORIES AS MODELS FOR EXPLORING OPERATIONAL AXIOMATIZATIONS OF QUANTUM MECHANICS.
Supervisor: Professor G. M. D'Ariano.

2004–2007 — **B. Sc. in Physics**, *University of Pavia*, Italy, *110/110 cum laude*.
Thesis title: SOLUZIONI DELL'EQUAZIONE DI SCHRÖDINGER IN SENSO DISTRIBUZIONALE E LORO COMPORTAMENTO ASINTOTICO
Supervisor: Prof. F. Capuzzi.

Supervision and teaching experience

Thesis co-supervision

2020 — L. Giannelli, Master thesis, University of Pavia, Italy, thesis title: BIT COMMITMENT IN OPERATIONAL PROBABILISTIC THEORIES.

2019 — M. Lugli, Master thesis, University of Pavia, Italy, thesis title: STATE DISCRIMINATION IN FERMIONIC THEORY.

2018 — L. Giannelli, Bachelor thesis, University of Pavia, Italy, thesis title: INFORMATION DISTURBANCE TRADE-OFFS IN QUANTUM THEORY.

2017 — M. Lugli, Bachelor thesis, University of Pavia, Italy, thesis title: MASS AND PROPER TIME AS CONJUGATED OBSERVABLES.

2014 — N. Mosco, Master thesis, University of Pavia, Italy, thesis title: EXACT SOLUTIONS OF THE WEYL AND DIRAC QUANTUM CELLULAR AUTOMATON.

2014 — M. Erba, Master thesis, University of Pavia, Italy, thesis title: NON-ABELIAN QUANTUM WALKS AND RENORMALIZATION.

Teaching activities

2013–2016 and 2017–2019 — **Teaching Assistant**, *University of Pavia*, Italy.
Taught exercises of FISICA (First Degree Course in Biology)

2013–2019 — **Tutor**, *University of Pavia*, Italy.
Taught exercises of FISICA GENERALE 2 (electromagnetism) (First Degree Course in Mathematics)

2011–2013 — **Tutor**, *University of Pavia*, Italy.
Taught exercises of FISICA (First Degree Course in Medicine)

Scientific activity

Editorial board

- Guest editor of the Special Issue on "Quantum Cellular Automata and Quantum Walks" published in journal Condensed Matter link.

Conferences attendance and organization

- More than 20 talks (including invited talks) at international conferences.

- Organizer of the "Quantum Foundations Workshop", June 21-22, 2016, University of Pavia, Italy link.

Dissemination

- Ten days physics for teenagers 2020, University of Pavia: seminar with title "Dalla macchina di Turing al computer quantistico".
- European Research Night 2019: stand on physics and mathematics of bubble soap.

Long term visits

- 5-13 December 2015, Centre for Quantum Technologies, National University of Singapore, Singapore. Host: Prof. Vlatko Vedral.

Reviewer for international journals

- Among others: Phys. Rev. Lett., Phys. Rev. A, Proc. Roy. Soc., IOP New J. of Phys., J. Phys. A, IEEE Transactions on Cybernetics, QINP, Entropy, ROMP, Symmetry, FOOP, others.

Computer skills

OS	Unix, Mac-OS, Windows
Programming languages	Pascal (high-school), Perl (B. Sc), C/C++ (B. Sc), LaTeX, HTML
Software	Wolfram Mathematica

Languages

Italian	Native language
English	Advanced

Presentations at conferences

Talks and seminars

September 14-18, 2020	Workshop on Quantum Information, Computation, and Foundation (online), Kyoto, Japan, *"information and disturbance in operational probabilistic theories"* (invited talk)
July 10-14, 2019	Quantum Causal Structures, Oxford, United Kingdom, *"Information and disturbance in a physical theory"* (talk)
June 10-14, 2019	16th International Conference on Quantum Physics and Logic, Chapman University, Orange, CA, United States, *"Information and disturbance in a physical theory"* (talk)
June 10-14, 2019	16th International Conference on Quantum Physics and Logic, Chapman University, Orange, CA, United States, *"Data-Driven Inference, Reconstruction, and Observational Completeness of Quantum Devices"* (talk)
May 24-June 1, 2019	Quantum 2019, Turin, Italy, *"Thirring quantum cellular automaton"* (talk)

July 16-20, 2018	14th Biennial Conference on Quantum Structures, Kazan, Russia, *"No-Hypersignaling Principle"* (talk)
July 2-5, 2018	Is quantum theory exact? The quest for the spin-statistics connection violation and related items, Frascati, Italy, *"No-hypersignaling principle"* (invited talk)
November 29-December 1, 2017	Workshop Quantum Foundations: New frontiers in testing quantum mechanics from underground to the space, Frascati, Italy, *"The Thirring quantum cellular automaton"* (invited talk)
July 3-7, 2017	14th International Conference on Quantum Physics and Logic, Nijmegen, The Netherlands, *"No-Hypersignaling as a Physical Principle"* (talk)
June 12, 2017	Quantum Simulation Models Workshop, Marseille, France, *"The Hubbard Fermionic quantum walk"* (invited talk)
March 20, 2017	Seminar on quantum computation, Sia S.p.a., Milan, Italy, *"Computer quantistico"* (invited talk)
July 11-15, 2016	Conference Quantum Algebras, Quantum Integrable Models and Quantum Information, The Lovén Centre Kristineberg, Sveden, *"The Hubbard Fermionic quantum walk"* (talk)
December 6-13, 2015	Visit at the Centre for Quantum Technology, National University of Singapore, Singapore, *"The Fermionic quantum theory and the Hubbard Fermionic quantum walk"* (invited talk)
November 16-18, 2015	Workshop of quantum Simulation and Quantum Walks, Yokohama National University, Japan, *"Quantum walks without coin: the role of the lattice in determining the walk dynamics"* (talk)
July 13-17, 2015	12th International Workshop on Quantum Physics and Logic, Oxford, United Kingdom, *"Fermionic quantum theory and superselection rules for operational probabilistic theories"* (talk)
June 15-17, 2015	47 Symposium on Mathematical Physics, Torun, Poland, *"Quantum walks without coin: the role of the lattice in determining the walk dynamics"* (talk)
September 15-19, 2014	Seventh International Workshop DICE2014, Castiglioncello, Italy, *"Discrete path integral solution for Dirac and Weyl quantum cellular automata"* (talk)
July 15-18, 2014	Frontiers of Fundamental Physics 14, Marseille, France, *"Informational features of Fermionic systems"*(talk)
June 5-8, 2014	11th Central European Quantum Information Processing Workshop, Znojmo, Czech Republic, *"The Feynman problem and Fermionic entanglement: Fermionic theory versus qubit theory"* (talk)
February 6-7, 2014	Meeting on Relativistic Quantum Walks, Université de Grenoble, France, *"The Fermionic Quantum theory"* (talk)

Other presentations

June 16-17, 2011	8th Canadian Student Conference on Quantum Information, Sherbrooke University, Canada, *"Probabilistic toy theories"* (poster)
May 9-13, 2011	Conceptual Foundations and Foils for Quantum Information Processing, Perimeter Institute, Waterloo Canada, *"Probabilistic toy theories"* (poster)

Publications

Google Scholar: https://scholar.google.it/citations?user=pIDs520AAAAJ
ORCID: https://orcid.org/0000-0001-8599-4427

Published – Peer reviewed

1. M. Lugli, P. Perinotti, A. Tosini, *Unambiguous discrimination of Fermionic states through local operations and classical communication*, Accepted in Phys. Rev. A, arXiv:2009.05657 (2020)
2. Michele Dall'Arno, Francesco Buscemi, Alessandro Bisio, Alessandro Tosini, *Data-Driven Inference, Reconstruction, and Observational Completeness of Quantum Devices*, Phys. Rev. A **102**, 062407 (2020) (2020)
3. G. M. D'Ariano, P. Perinotti, A. Tosini, *Information and disturbance in operational probabilistic theories*, Quantum **4**, 363 (2020)
4. M. Lugli, P. Perinotti, A. Tosini, *Fermionic state discrimination by local operations and classical communication*, Phys. Rev. Lett. **125**, 110403 (2020)
5. Alessandro Bisio, Giacomo Mauro D'Ariano, Nicola Mosco, Paolo Perinotti, Alessandro Tosini, *Solutions of a Two-Particle Interacting Quantum Walk*, Entropy 20(6), 435 (2018)
6. Alessandro Bisio, Giacomo Mauro D'Ariano, Paolo Perinotti, Alessandro Tosini, *Thirring quantum cellular automaton*, Phys. Rev. A **97**, 032132 (2018)
7. Giacomo Mauro D'Ariano, Nicola Mosco, Paolo Perinotti, Alessandro Tosini, *Path-sum solution of the Weyl quantum walk in 3+1*, Philosophical Transactions A **375** 2106 (2017)
8. Michele Dall'Arno, Sarah Brandsen, Alessandro Tosini, Francesco Buscemi, Vlatko Vedral, *No-hypersignaling principle*, Phys. Rev. Lett. **119** 020401 (2017)
9. Giacomo Mauro D'Ariano, Marco Erba, Paolo Perinotti, Alessandro Tosini, *Virtually Abelian quantum walks*, J. Phys. A, **50**, 035301 (2017)
10. Giacomo Mauro D'Ariano, Nicola Mosco, Paolo Perinotti, Alessandro Tosini, *Discrete Time Dirac Quantum Walk in 3+1 Dimensions*, Entropy **18** 228 (2016)
11. A. Bisio, G. M. D'Ariano, M. Erba, P. Perinotti, A. Tosini, *Quantum walks with a one-dimensional coin*, Phys. Rev. A **93** 062334 (2016)
12. A. Bisio, G. M. D'Ariano, P. Perinotti, A. Tosini, *Free Quantum Field Theory from Quantum Cellular Automata. Derivation of Weyl, Dirac and Maxwell Quantum Cellular Automata*, Foundations of Physics, Volume **45**, Issue 10, pp 1137-1152 (2015)
13. A. Bisio, G. M. D'Ariano, P. Perinotti, A. Tosini, *Weyl, Dirac and Maxwell Quantum Cellular Automata. Analytical Solutions and Phenomenological Predictions of the Quantum Cellular Automata Theory of Free Fields*, Foundations of Physics, Volume **45**, Issue 10, pp 1203-1221 (2015)
14. A. Bibeau-Delisle, A. Bisio, G. M. D'Ariano, P. Perinotti, A. Tosini, *Doubly special relativity from quantum cellular automata*, EPL **109** 50003 (2015)
15. G. M. D'Ariano, N. Mosco, P. Perinotti, A. Tosini, *Discrete Feynman propagator for the Weyl quantum walk in 2+1 dimensions*, EPL **109** 40012 (2015)
16. A. Bisio, G. M. D'Ariano, A. Tosini, *Quantum field as a quantum cellular automaton: the Dirac free evolution in one dimension*, Annals of Physics **354** 244 (2015)
17. G. M. D'Ariano, N. Mosco, P. Perinotti, A. Tosini, *Path-integral solution of the one-dimensional Dirac quantum cellular automaton*, Phys. Lett. A **378** 3165 (2014)
18. G. M. D'Ariano, F. Manessi, P. Perinotti, A. Tosini, *The Feynman problem and fermionic entanglement: Fermionic theory versus qubit theory*, Int. J. Mod Phys. A **17** 1430025 (2014)
19. G. M. D'Ariano, F. Manessi, P. Perinotti, A. Tosini, *Fermionic computation is non-local tomo-*

graphic and violates monogamy of entanglement, EPL **107** 20009 (2014)

20. A. Bisio, G. M. D'Ariano, A. Tosini, *Dirac quantum cellular automaton in one dimension: Zitterbewegung and scattering from potential*, Phys. Rev A **88** 032301 (2013)
21. A. Tosini, *A Quantum Cellular Automata Framework for Quantum Fields Dynamics*, Scientifica Acta 7, No. 1, Ph 21-30 (2013)
22. G. M. D'Ariano, A. Tosini, *Emergence of space-time from topologically homogeneous causal networks*, Studies in History and Philosophy of Modern Physics **44** 294 (2013)
23. G. M. D'Ariano, A. Tosini, *Testing axioms for quantum theory on probabilistic toy-theories*, Quant. Inf. Proc. **9** 95-141 (2010)

Research activity and summary of the scientific results

Since the PhD my research activity focused on the theoretical aspects of quantum theory and quantum information. I actively contributed to the development of the framework of operational probabilistic theories. In parallel I was interested in foundational issues in quantum field theory from the perspective of quantum information theory. In collaboration with the QUIT group, I started a project aimed to the information theoretic reconstruction of quantum field theory based on the quantum cellular automata formalism. Below the main scientific results.

Operational probabilistic theories and quantum information

In quantum foundations one compares the characteristic quantum traits with other in principle admissible behaviours, seeking physical grounds for the axioms of quantum theory. To this end, a natural playground is that of operational probabilistic theories (OPTs): here a rigorous formulation of the notions of system, process, and their compositions is given, which constitutes the grammar for the probabilistic description of an experiment. Quantum theory and classical theory are two instances of OPTs.

I) I provided one of the first thorough formalization of the Popescu-Rohrlich boxes as a consistent probabilistic theory. The Popescu-Rohrlich boxes are a popular example of probabilistic model that exhibits spacelike correlations stronger than the quantum ones but still no-signaling: they cannot be harnessed to make instantaneous (faster than light) communication possible, thus respecting special relativity.

II) I developed an OPT having Fermions as elementary systems. This allows to compare Fermionic systems and "qubits" on the same playground clarifying the old issue of simulating Fermionic quantum fields (anticommuting systems) by a quantum computer (which operates with commuting systems). While Fermionic theory and quantum theory can simulate each other, they differ in the notion of locality: Fermionic theory does not coincide with quantum theory with parity super-selection rule. The parity super-selection, which forbids the superposition of states with an even and an odd number of particles, was originally introduced by Wick, Wightman, and Wigner by spacetime symmetry arguments. Here, the same rule has been derived from the operational notion of locality in a probabilistic theory: operations on systems that are not causally connected must commute.

III) I proved, in collaboration with CQT in Singapore and Nagoya University, that any approach to characterize quantum theory based only on its space-like correlations (entanglement) is necessarily incomplete unless it also takes into account time-like correlations. A characteristic trait of a physical theory are the correlations it allows and their relation with the casual structure of spacetime. One of the main tenets in modern physics (no-signaling principle) is that space-like correlations must not carry any information. In order to describe quantum time-like correlations we introduced the "no-hypersignaling principle": any input/output correlation that can be obtained by transmitting a composite system should also be obtainable by independently transmitting its constituents. As space-like quantum correlations must be no-signaling, quantum time-like correlations must satisfy the no-hypersignaling condition. While quantum theory obeys no-hypersignaling, we provided a toy model that, though being perfectly compatible with classical and quantum theories at the level of spacelike correlations, displays an anomalous behavior, *hypersignaling*, in its timelike correlations. This theory would go undetected in any test involving only spacelike correlations.

IV) I studied the computational features of Fermionic systems, leading to a characterization of Fermionic entanglement and tomography of Fermionic states. Looking at Fermions as the systems of a computational

model led to a precise notion of Fermionic entanglement and to an appropriate operational way to quantify it via the Fermionic entanglement of formation. As a main result it is proved that, due to the parity super-selection, the quantum informational features of Fermionic systems differ from the one of commuting quantum systems. First Fermionic entanglement do not show monogamy, i.e. the limitation on the sharing of entanglement between many parties, second Fermionic systems does not satisfy local tomography, i.e. the possibility of discriminating between two nonlocal states using only local measurements. However, bi-local protocols have been proven to suffice. Another relevant result is that, contrarily to the case of quantum systems, for Fermionic systems it is generally not possible to achieve the ideal state discrimination performances through local operations and classical communication (LOCC) measurements. However, it is shown that an ancillary system made of two Fermionic modes in a maximally entangled state is a sufficient additional resource to attain the ideal performances via LOCC measurements.
V) A recent achievement is an original proof of the no-information without disturbance relation, namely the core feature at the basis of Heisenberg uncertainty relations. Similarly to the Heisenberg uncertainty relations, the no-information without disturbance has been considered as a characteristic quantum trait. Instead, it is shown that this feature can be exhibited in the absence of most of the principles of quantum theory, and it is ubiquitous among operational probabilistic theories. We also proved that the only systems that allow to extract any information without disturbance are classical systems.

Quantum cellular automata and discrete quantum field theory

Starting with the Lamb shift (1940s) and peaking in the experimental tests of the standard model, perturbatively renormalised quantum field theory (QFT) has proved its remarkable predictive power. However, the structure of the standard model is deeply rooted in its perturbative expansion and this raises questions of consistency of the full theory. The perturbative series is known to diverge and even in the simplest prototypical ϕ^4 interaction the perturbative expansion is misleading since the theory has been proved to be *trivial* in dimension 3+1: the quantum counterpart of a classical interacting theory may be inconsistent at high momenta unless the renormalised charge is set to zero, namely the quantum theory actually describes non-interacting fields. These issues prevent a consistent definition of QFT in terms of its perturbative expansion. On the other hand a non-trivial example of QFT in 3+1 dimensions that allows for a non-perturbative control is still laking. These issues may be caused by our lack of knowledge of the small scale physics and QFT may represent an effective theory. A mathematical foundation to relativistic quantum field theory was given by Gårding and Wightman, and later in the algebraic and constructive/euclidean quantum field theory frameworks. While this axiomatic setup allows to describe quantum fields on curved spacetime, the process of reconstruction has faced severe difficulties in including fields interaction. Among the axioms it appears Poincaré covariance, although it can be verified only in the perturbative regime. Within an axiomatic approach to the foundations of interacting fields one can question whether interactions break the free theory symmetries.
In collaboration with the Quit group I developed a discrete model for quantum fields dynamics based on quantum circuits for the time evolution. The circuit architecture used in this framework is that of quantum walks, for the free evolution, and of quantum cellular automata, for the interacting case. The last ones are also capable to design implementable quantum simulators for quantum fields. Quantum simulators allow to analyse physical systems in a detail hard to address in the lab, and cannot be achieved by a classical computer, due to their exponential complexity in terms of classical resources. I significantly contributed to:
I) The development of a quantum walk theory for free Fermionic fields.
II) The analytical solution of a quantum cellular automaton model for the four-fermion interaction, showing the effects of a discrete time dynamics on both scattering and bound states solutions.
III) The derivation of the deformed Poincaré symmetry compatible with the invariance of the automaton dynamics under change of reference frame. The consistency with the Poincaré symmetry is proved in the low energy limit.
IV) The analysis of the admissible quantum field dynamics on a given graph, providing a no-go theorem for scalar fields on abelian graphs.
V) The development of a discrete path-integral formulation of the automaton model.

I, ALESSANDRO TOSINI, born in BRESCIA (BS) on 27/06/1985, resident in via Bordoncina n.7, PAVIA (IT), declare under penalty of perjury subject to all applicable laws (art.76 D.P.R. 28/12/2000 n.445), that the information provided is true and correct to the best of my knowledge, information and belief.
I authorize the use of my personal data in compliance with D.L. 196/03.

January 7, 2021