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Alessandro Tosini

Research Assistant

Personal information

Via Bordoncina 7, Pavia 27100, Italy

Italian, Born on 27^{th} of June 1985, Brescia, Italy

1 children

Research Fields and Aims

Theoretical aspects of quantum computation and quantum information theory.

Quantum simulators.

Quantum causal networks.

Academic Positions

April 2021–present **Research Assistant**, *Quantum information theory group, University of Pavia*, Italy.

2010–present **INFN scientific associate**, *INFN sezione di Pavia*, Italy.

December 2019–March 2021 **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.

Degrees

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

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 School on Quantum Information**, *Sherbrooke University*, Canada, Final exam evaluation: A+.

2007–2009 **M.Sc. in Theoretical Physics**, *University of Pavia*, Italy, *110 and honors*.
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 and honors*.
Thesis title: *Distributional solutions of the Schrödinger equation and their asymptotic behavior*
Supervisor: Prof. F. Capuzzi.

Supervisions/co-supersvision and teaching activities

PhD students

2022–present D. Rolino, PhD in Physics, University of Pavia, Italy.

2020–2023 M. Lugli, PhD in Physics, University of Pavia, Italy.

Thesis supervisions and co-supervisions

2023 S. Coppola, Licence thesis, University of Pavia, Italy. thesis title: *Cellular automata: structure and applications.*

2022 D. Rolino, Master thesis, University of Pavia, Italy. thesis title: *A classical theory with incompatible measurements.*

2021 L. Giannelli, University School for Advanced Studies IUSS Pavia, Italy, thesis title: *Entanglement and bit commitment.*

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

2023–present Chair for "Laboratory of quantum information" (36 hours), undergraduate course in Artificial Intelligence for Science and Technology, University of Milan, the University of Pavia and the University of Milano-Bicocca, Italy.

2022–present Assistant Professor of "Quantum Mechanics" (24 hours), undergraduate course in Physics, University of Pavia, Italy.

2022–present Assistant Professor of "Analytical mechanics" (24 hours), undergraduate course in Physics, University of Pavia, Italy.

2022 Chair of "Advanced topics in quantum computation", Phd level course (PhD in Physics and Physics of Quantum Technologies), University of Pavia, Italy.

2017–2019 Assistant for the course of Physics, undergraduate course in Biology, University of Pavia, Italy

2013–2019 Assistant for the course of Electromagnetism, undergraduate course in Mathematics, University of Pavia, Italy

2013–2016 Assistant for the course of Physics, undergraduate course in Biology, University of Pavia, Italy

2011–2013 Assistant for the course of Physics, undergraduate course in Medicine, University of Pavia, Italy

Scientific production and scientific activities

Editorial board

- Editor of the Special Issue on "Symmetries in Quantum Information: Fundamental Aspects and Applications" published in journal Symmetry link.
- Since 2021 part of the topic board of Symmetry link.
- Editor of the Special Issue on "Quantum Cellular Automata and Quantum Walks" published in journal Condensed Matter link.

Publications

- More than 28 articles in international-level refereed journals.

Conferences attendance and organization

- More than 27 talks (including 10 invited talks) at international-level refereed conferences and workshops.
- Organizer of the "Quantum Foundations Workshop", June 21-22, 2016, University of Pavia, Italy link.

Reviewer for international journals

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

Selected research invitations

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

Collaborative networks and projects

2020-present **The observer: an operational theoretical approach**, *Silicon Valley Community Foundation Research Project ID#2020-214365*, I was member of the research team (and contributed to the submission of the proposal).

2016-2019 **Quantum Causal Structures**, *Templeton Foundation Research Project ID#60609*, I was member of the research team (and contributed to the submission of the proposal).

2013-2016 **A Quantum-Digital Universe**, *Templeton Foundation Research Project ID#43796*, I was member of the research team (and contributed to the submission of the proposal).

Scientific dissemination

- Ten days physics for teenagers 2020, University of Pavia: seminar with title "From Turing machine to quantum computer" (2020).
- European Research Night 2019: activity and presentation on"Physics and mathematics of bubble soap" (2019).
- Orientation to undergraduate students in Physics, University of Pavia: seminar with title "The quantum imitation game" (2019).
- Member of the scientific staff for the event "Physics and mathematics of bubble soap" at the cultural club "Circolo Via d'acqua", Pavia, Italy (2019)

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- Invited colloquium on "Quantum computation" at Sia S.p.a., Milan, Italy (2017)
- Reception and orientation of high school students: seminar on "Quantum information theory" (2013).

Major contributions

Quantum walks and quantum cellular automata simulators, Quantum simulators allow to analyse physical that cannot be simulated by classical computer due to their exponential complexity. I developed quantum causal networks for the simulations of quantum field theories. The causal network architecture is that of quantum walks for free particles simulation, and of quantum cellular automata for interacting fields. My main results are i) A quantum walk formulation of free quantum field theory, including a combinatorial discrete path-integral for quantum walks and an impossibility theorem for scalar fields (local one-dimensional system) on abelian (e.g. square) lattices; ii) The analytical solution of a quantum cellular automaton model for the four-fermion interaction, showing for the first time the features of discrete time particles scattering and bound states formation; iii) The proof that, despite the discreteness of the quantum network, the symmetry of the automaton operator corresponds to a non-linear version of the usual continuous spacetime Lorentz symmetry, which is indeed obtained in the continuum limit.

Fermionic quantum computation, A long-standing issue is the simulation of fermionic systems by a quantum computer. Indeed the operators describing two separated fermions anti-commute, while operators on two different qubits commute. Accordingly, if qubits are used to simulate fermions, local operations on qubits become non local on fermions and vice-versa. This prevents from a simple understanding of the informational features of fermions as carriers of information. I introduced a consistent information theory having fermions as elementary systems and studied extensively its computational properties and performances in informational tasks. The parity super-selection rule, which follows from the anti-commuting fermionic algebra and forbids the superposition of states with an even and an odd number of particles, has been understood in computational terms and derived from the locality of fermionic quantum operations. Fermionic entanglement and local operations and classical communication (LOCC) state discrimination protocols have been characterized.

Quantum correlations, A characteristic trait of an information theory are the correlations it allows in relation to the causal structure of spacetime. A main tenet is the no-signaling principle, saying that spacelike correlations must not propagate any information. However, this does not single out quantum entanglement, since there exist correlations stronger than the quantum ones but still no-signaling. I provided one of the first formalization of an information theory with those strong correlations, showing that stronger than quantum correlations lead to several weaknesses with respect to entanglement, such as the impossibility of teleportation. I also proved that any approach to characterize quantum theory based only on spacelike correlations is incomplete, unless it also takes into account timelike correlations. To describe quantum timelike correlations we introduced the "no-hypersignaling" criterion: any input/output correlation obtained by a composite system should also be obtainable by independently transmitting its constituents.

Quantum information-disturbance trade-off and unified resource theory for quantum incompatibility, I gave an original proof of the quantum no-information without disturbance relation, the core feature at the basis of Heisenberg uncertainty relations. No-information without disturbance theorem 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 features of quantum theory. A structure theorem showing that the set of states of any theory is in block form, were the information encoded inside each block cannot be obtained without disturbance, while the information on "which is the block?" can be read without disturbance. I also proved that the only systems that allow to extract any information without disturbance are classical systems. I formalized two notions of incompatibility of quantum devices, based on parallel and sequential simulability, respectively. While incompatibility of POVMs is unambiguously defined, instruments allows for different and logically independent definitions of incompatibility. We close this gap by unifying different notions of POVMs, channels, and instruments incompatibility into one hierarchy of resource theories of communication between separated parties. Based on this result it is possible to understand what each notion of incompatibility consists of, in terms of information-theoretic resources.

Data-driven inference of quantum devices, Conventional quantum tomography aims at the reconstruction of an unknown device from the statistics collected in a sequence of experimental trials via a known and trusted input. We introduced an alternative procedure for the inference of an unknown quantum device that only requires the analysis of the bare outcome distributions: the source could, for example, emit a different unknown input at each run of the experiment. We introduced data-driven inference as a protocol that, given a set of experimental data, infers the quantum device which is, i) consistent with the data, and, ii) maximally noncommittal.

Generalized Shannon theory, We introduced a quantity, named "information content", that generalizes Shannon entropy of classical systems and von Neumann entropy of quantum systems to systems of an arbitrary theory of information processing. While classical and quantum theories are monoentropic, a general information theory admits several inequivalent entropic quantities. The information content of a source, as the minimal support needed to store the output of the source in a perfectly recoverable way, is proved to be the natural entropic quantity generalizing Shannon entropy to every physical system encoding information.

Computer skills

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

Languages

Italian	Native language
English	Advanced

List of presentations at conferences and workshops

Invited talks and seminars

June 1-10, 2024	Quantum Matter 2024, San Sebastian, Spain, *"Causal influence versus signalling for interacting quantum channels"*
July 4, 2023	Invited seminar, ICTQT, Gdańsk, *"Incompatibility of instruments in quantum theory and beyond"*
January 20, 2022	Invited seminar (online), QuaCS team in Paris, France, *"Structures underlying quantum computing and Quantum simulators for quantum fileds"*
September 13-17, 2021	Workshop on Quantum Information, Computation, and Foundation (online), Kyoto, Japan, *"Incompatibility of instruments in operational probabilistic theories"*
June 4, 2021	Invited seminar (online), RCQI, Bratislava, Slovakia, *"information and disturbance in operational probabilistic theories"*
September 14-18, 2020	Workshop on Quantum Information, Computation, and Foundation (online), Kyoto, Japan, *"information and disturbance in operational probabilistic theories"*
July 2-5, 2018	Is quantum theory exact? The quest for the spin-statistics connection violation and related items, Frascati, Italy, *"No-hypersignaling principle"*
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"*
June 12, 2017	Quantum Simulation Models Workshop, Marseille, France, *"The Hubbard Fermionic quantum walk"*
March 20, 2017	Seminar on quantum computation, Sia S.p.a., Milan, Italy, *"Computer quantistico"*
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"*

Selected talks at international-level conferences

November 10-12, 2023	10th International Workshop on Quantum Simulation and Quantum Walks, Tsukuba, Japan, *"Continuity of causal influence versus signalling, from quantum walks to inter- acting quantum channels"*
September 12-16, 2022	14th Italian quantum information science conference, Palermo, Italy, *"Incompatibility of quantum measurements, channels and instruments"*
June 27-July 2, 2022	15th Biennial Quantum Structure 2022 Conference, Tropea, Italy, *"Incompatibility of quantum measurements, channels and instruments"*

July 10-14, 2019 — Quantum Causal Structures, Oxford, United Kingdom, *"Information and disturbance in a physical theory"*

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"*

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"*

May 24-June 1, 2019 — Quantum 2019, Turin, Italy,*"Thirring quantum cellular automaton"*

July 16-20, 2018 — 14th Biennial Conference on Quantum Structures, Kazan, Russia, *"No-Hypersignaling Principle"*

July 3-7, 2017 — 14th International Conference on Quantum Physics and Logic, Nijmegen, The Netherlands, *"No-Hypersignaling as a Physical Principle"*

July 11-15, 2016 — Conference Quantum Algebras, Quantum Integrable Models and Quantum Information, The Lovén Centre Kristineberg, Sveden, *"The Hubbard Fermionic quantum walk"*

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"*

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"*

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"*

September 15-19, 2014 — Seventh International Workshop DICE2014, Castiglioncello, Italy, *"Discrete path integral solution for Dirac and Weyl quantum cellular automata"*

July 15-18, 2014 — Frontiers of Fundamental Physics 14, Marseille, France, *"Informational features of Fermionic systems"*

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"*

February 6-7, 2014 — Meeting on Relativistic Quantum Walks, Université de Grenoble, France, *"The Fermionic Quantum theory"*

Other presentations

June 16-17, 2011 — 8th Canadian Student Conference on Quantum Information, Sherbrooke University, Canada, *"Probabilistic toy theories"*

May 9-13, 2011 — Conceptual Foundations and Foils for Quantum Information Processing, Perimeter Institute, Waterloo Canada, *"Probabilistic toy theories"*

List of publications

Google Scholar: https://scholar.google.it/citations?user=plDs520AAAAJ

ORCID: https://orcid.org/0000-0001-8599-4427
In the following the full list of publications, including papers on leading journals as Phys. Rev. Lett. and Quantum.

Submitted

1. Paolo Perinotti, Alessandro Tosini, Leonardo Vaglini, *Continuity of causal influence versus signalling for interacting quantum channels*, arXiv:2309.07771 (2023)

Published – Peer reviewed

2. Michele Dall'Arno, Alessandro Tosini, Francesco Buscemi *The signaling dimension in generalized probabilistic theories*, Quantum Information and Computation, Vol. 24, No. 5&6, 0411-0424 (2024)
3. Marco Erba, Paolo Perinotti, Davide Rolino, Alessandro Tosini, *Measurement incompatibility is strictly stronger than disturbance*, Phys. Rev. A **109**, 022239 (2024)
4. Paolo Perinotti, Alessandro Tosini, Leobardo Vaglini *Which entropy for general physical theories?*, arXiv:2305.16931 (2023), accepted on Quantum
5. Paolo Perinotti, Alessandro Tosini, Leonardo Vaglini, *Shannon theory for quantum systems and beyond: information compression for fermions*, In: Plotnitsky, A., Haven, E. (eds) The Quantum-Like Revolution, Springer (2023)
6. Francesco Buscemi, Kodai Kobayashi, Shintaro Minagawa, Paolo Perinotti, Alessandro Tosini, *Unifying different notions of quantum incompatibility into a strict hierarchy of resource theories of communication*, Quantum **7**, 1035 (2023) (2023)
7. G. M. D'Ariano, P. Perinotti, A. Tosini, *Incompatibility of observables, channels and instruments in information theories*, J. Phys. A **55**, 394006 (2022)
8. Paolo Perinotti, Alessandro Tosini, Leonardo Vaglini, *Shannon theory beyond quantum: information content of a source*, Phys. Rev. A. **105**, 052222 (2022)
9. Matteo Lugli, Paolo Perinotti, Alessandro Tosini, *Unambiguous discrimination of fermionic states through local operations and classical communication*, Phys. Rev. A **103**,012416 (2021)
10. 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)
11. G. M. D'Ariano, P. Perinotti, A. Tosini, *Information and disturbance in operational probabilistic theories*, Quantum **4**, 363 (2020)
12. M. Lugli, P. Perinotti, A. Tosini, *Fermionic state discrimination by local operations and classical communication*, Phys. Rev. Lett. **125**, 110403 (2020)
13. 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)
14. Alessandro Bisio, Giacomo Mauro D'Ariano, Paolo Perinotti, Alessandro Tosini, *Thirring quantum cellular automaton*, Phys. Rev. A **97**, 032132 (2018)
15. 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)
16. Michele Dall'Arno, Sarah Brandsen, Alessandro Tosini, Francesco Buscemi, Vlatko Vedral, *No-hypersignaling principle*, Phys. Rev. Lett. **119**, 020401 (2017)
17. Giacomo Mauro D'Ariano, Marco Erba, Paolo Perinotti, Alessandro Tosini, *Virtually Abelian quantum walks*, J. Phys. A **50**, 035301 (2017)
18. Giacomo Mauro D'Ariano, Nicola Mosco, Paolo Perinotti, Alessandro Tosini, *Discrete Time Dirac Quantum Walk in 3+1 Dimensions*, Entropy **18**, 228 (2016)

19. 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)
20. 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)
21. 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)
22. A. Bibeau-Delisle, A. Bisio, G. M. D'Ariano, P. Perinotti, A. Tosini, *Doubly special relativity from quantum cellular automata*, EPL **109**, 50003 (2015)
23. 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)
24. 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)
25. 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)
26. 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)
27. G. M. D'Ariano, F. Manessi, P. Perinotti, A. Tosini, *Fermionic computation is non-local tomographic and violates monogamy of entanglement*, EPL **107**, 20009 (2014)
28. 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)
29. A. Tosini, *A Quantum Cellular Automata Framework for Quantum Fields Dynamics*, Scientifica Acta 7, No. 1, Ph 21-30 (2013)
30. 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)
31. G. M. D'Ariano, A. Tosini, *Testing axioms for quantum theory on probabilistic toy-theories*, Quant. Inf. Proc. **9**, 95-141 (2010)

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.

June 7, 2024