Alberto Fachechi

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Activity and research interests

My research activity is placed in the wide discipline of statistical mechanics methods for complex systems analysis, in particular concerning **spin-glass theory** and its application to modern **Artificial Intelligence** and **Machine Learning**. The core research interest consists in the development of rigorous mathematical techniques, involving in particular Guerra's interpolating schemes, non-linear PDE theory, probability and statistics and random matrix theory. My research interests also cover the application of statistical inference tools to real-world (in particular, biological) problems.

Positions

2023 – Today
- **Researcher** (RTD-A).
  Department of Mathematics G. Castelnuovo, Sapienza University of Rome.

2021 – 2023
- **Post-doc researcher.**
  Department of Mathematics G. Castelnuovo, Sapienza University of Rome.

2020 – 2021
- **Post-doc researcher.**
  Department of Mathematics and Physics E. De Giorgi, Unisalento.

2019 – 2020
- **Research fellow.**
  Department of Mathematics and Physics E. De Giorgi, Unisalento.

Education

2016 – 2019
- **Ph.D. in Physics and Nanosciences.**
  Department of Mathematics and Physics E. De Giorgi, Unisalento.
  Thesis title: *Statistical mechanics for Artificial Intelligence: Learning, Retrieving, Unlearning and Sleeping.*

2013 – 2015
- **M.Sc. in Theoretical Physics of Fundamental Interactions.**
  Department of Mathematics and Physics E. De Giorgi, Unisalento.
  Thesis title: *Higher-spin Lifshitz theories and integrable systems.*

2009-2013
- **B.Sc. in Physics.**
  Department of Mathematics and Physics E. De Giorgi, Unisalento.
  Thesis title: *Integrability in AdS/CFT.*

Communities

2023-Today
- **FAIR foundation (Future Artificial Intelligence Research).**
  Partecipation as researcher in the group of Artificial Intelligence at Department of Mathematics, Sapienza University of Rome.

2018-Today
- **National Group for Mathematical Physics (GNFM-INdAM)**, section of mechanics for discrete systems.

2016-2017
- **GATIS (GAuge Theory as an Integrable System)**, section of Bologna, National Institute for Nuclear Physics (INFN).

2015-2021
- **National Institute for Nuclear Physics (INFN)**, section of Lecce.

Teaching

2023-2024
- Co-lecturer for the course of **Calculus and Biostatistics** for the academic year 2023-2024 (together with Prof. Elena Agliari), Department of Biology and Biotechnologies, Sapienza University of Rome.
- Teaching assistant for the course of **Elements of Probability and Statistics for Data Science** for the year 2023-2024 (resp. Prof. Alessandra Faggionato), Department of Mathematics, Sapienza University of Rome.
- Lecturer for the course of **Statistical learning and neural networks: a short introduction to Artificial Intelligence** for the academic year 2023-2024 in the context of the "Excellence Program", Department of Mathematics, Sapienza University of Rome.

2021-2022
- Co-lecturer for the course of **Mathematics** for the academic year 2021-2022 (resp. Prof. Raffaela Capitanelli), Department of Architecture, Sapienza University of Rome.

2020-2021
- Supervisor for the course of **Mathematics for Economy and Finance** for the academic years 2019-2020 and 2020-2021 (resp. Prof. Luca Anzilli), Department of Economy, Unisalento.

Supervising

2024
- Supervisor for the ACU course essay by Yuriy Dosyak with title *Bayesian approach to supervised learning: mathematical approaches to automatic learning*, Sapienza Università di Roma, Rome (IT).
- Co-supervisor (together with Prof. Elena Agliari) for the PhD thesis in Mathematics by Domenico Luongo with title *A Random Matrix Theory Perspective on Hebbian-Like Neural Networks*, Sapienza Università di Roma, Rome (IT).

2023
- Supervisor for the M.Sc. thesis in Mathematics by Benedetta Giovannelli with title *Statistical mechanics of spin-glasses for Artificial Intelligence and Machine*, Sapienza Università di Roma, Rome (IT).

2022-2023
- Co-supervisor (together with Prof. Elena Agliari) for the PhD thesis in Mathematics by Chiara Marullo with title *Rigorous techniques for Statistical Mechanics of Machine Retrieval*, Sapienza Università di Roma, Rome (IT).
- Co-supervisor (together with Prof. Elena Agliari) for the M.Sc. thesis in Mathematics by Donatella Genovese with title *Effective training strategies for Restricted Boltzmann Machines*, Sapienza Università di Roma, Rome (IT).
- Co-supervisor (together with Prof. Elena Agliari) for the M.Sc. thesis in Mathematics by Matteo Notarnicola with title *On the thermodynamic limit of bipartite spin glasses*, Sapienza Università di Roma, Rome (IT).

2018
- Co-supervisor (together with Prof. Elena Agliari) for the M.Sc. thesis in Applied Mathematics by Chiara Marullo with title *Neural network beyond the Hebbian paradigm*, Sapienza Università di Roma, Rome (IT).

Funded projects

2023
- PI for the project **Rigorous statistical mechanics for Artificial Intelligence and Machine Learning** in the context of Progetto Giovani 2023 funded by National Group of Mathematical Physics (GNFM).

2022
- PI for the project **Replica Symmetry Breaking in modern Artificial Intelligence** in the context of Progetto Avvio alla ricerca 2022 funded by Sapienza University of Rome.

Funded projects (continued)

- Partecipant to the project **Large scale multicomponent random systems** (ref. Prof. Vittoria Silvestri) funded by Sapienza University of Rome (Progetto di Ricerca Medio).

2018
- Partecipant to the project **Rigorous approaches to Deep Learning** (ref. Prof. Elena Agliari) in the context of Progetto Giovani 2018 funded by National Group of Mathematical Physics (GNFM).

Other roles

2024-Today
- **Responsible for communication** for the FAIR foundation, Spoke 5 (WP5.5) for the organization of scientific and dissemination events.

2024
- **Organizer** of the VI Scientific Meeting for the FAIR foundation.

2023-Today
- Member of the Department Assembly, Department of Mathematics, Sapienza University of Rome.

2022
- **Project reviewer** for the Isreal Science Foundation.

2018-Today
- **Review editor** for Frontiers in Physics, section of Social Physics.

2017-Today
- **Referee** for several high-impact journals, in particular *Nature Scientific Reports*; *Journal of Mathematical Physics*; *Journal of Physics A: Mathematical and Theoretical*; *Neural Computation*; *Journal of Physics: Complexity*; *Physica A: Statistical Mechanics and its Applications*; *Journal of Statistical Mechanics: Theory and Experiment*; *Machine Learning: Science and Technology*.

Recognitions

2023
- **Outstanding reviewer** for IOP publishing for my contributions to the *Journal of Physics: Complexity*.

2021
- **Special mention** for my PhD thesis from the selection board of Fubini Prize 2021 (INFN).

2020
- **Truster reviewer** for IOP Publishing.

Summary of scientific production

Total number of publications	27
Total number of citations[1]	388
Total h-index[1]	10
Total $i10$-index[1]	10

Full list of publications

Journal Articles

[1] E. Agliari, F. Alemanno, M. Aquaro, and **A. Fachechi**, "Regularization, early-stopping and dreaming: A hopfield-like setup to address generalization and overfitting," *Neural Networks*, vol. 177, p. 106 389, 2024.

[2] E. Agliari, **A. Fachechi**, and D. Luongo, "A spectral approach to hebbian-like neural networks," *Applied Mathematics and Computation*, vol. 474, p. 128 689, 2024.

[3] **A. Fachechi**, E. Agliari, M. Aquaro, A. Coolen, and M. Mulder, "Fundamental operating regimes, hyper-parameter fine-tuning and glassiness: Towards an interpretable replica-theory for trained restricted boltzmann machines," *arXiv preprint arXiv:2406.09924*, 2024.

[1] Source: GoogleScholar.

[4] E. Agliari, M. Aquaro, A. Barra, **A. Fachechi**, and C. Marullo, "From Pavlov conditioning to Hebb learning," *Neural Computation*, vol. 35, no. 5, pp. 930–957, 2023.

[5] F. Alemanno, M. Cavo, D. Delle Cave, *et al.*, "Quantifying heterogeneity to drug response in cancer–stroma kinetics," *Proceedings of the National Academy of Sciences*, vol. 120, no. 11, e2122352120, 2023.

[6] E. Agliari, **A. Fachechi**, and C. Marullo, "Nonlinear PDEs approach to statistical mechanics of dense associative memories," *Journal of Mathematical Physics*, vol. 63, no. 10, 2022.

[7] **A. Fachechi**, A. Barra, E. Agliari, and F. Alemanno, "Outperforming RBM feature-extraction capabilities by "dreaming" mechanism," *IEEE transactions on neural networks and learning systems*, vol. 35, no. 1, pp. 1172–1181, 2022.

[8] E. Agliari, L. Albanese, F. Alemanno, and **A. Fachechi**, "A transport equation approach for deep neural networks with quenched random weights," *Journal of Physics A: Mathematical and Theoretical*, vol. 54, no. 50, p. 505 004, 2021.

[9] **A. Fachechi**, "PDE/statistical mechanics duality: Relation between Guerra's interpolated p-spin ferromagnets and the Burgers hierarchy," *Journal of Statistical Physics*, vol. 183, no. 1, p. 12, 2021.

[10] E. Agliari, F. Alemanno, A. Barra, M. Centonze, and **A. Fachechi**, "Neural networks with a redundant representation: Detecting the undetectable," *Physical review letters*, vol. 124, no. 2, p. 028 301, 2020.

[11] E. Agliari, F. Alemanno, A. Barra, and **A. Fachechi**, "Generalized Guerra's interpolation schemes for dense associative neural networks," *Neural Networks*, vol. 128, pp. 254–267, 2020.

[12] E. Agliari, F. Alemanno, A. Barra, *et al.*, "Analysis of temporal correlation in heart rate variability through maximum entropy principle in a minimal pairwise glassy model," *Scientific Reports*, vol. 10, no. 1, p. 15 353, 2020.

[13] E. Agliari, A. Barra, O. A. Barra, **A. Fachechi**, L. Franceschi Vento, and L. Moretti, "Detecting cardiac pathologies via machine learning on heart-rate variability time series and related markers," *Scientific Reports*, vol. 10, no. 1, p. 8845, 2020.

[14] E. Agliari, **A. Fachechi**, and C. Marullo, "The relativistic Hopfield model with correlated patterns," *Journal of Mathematical Physics*, vol. 61, no. 12, 2020.

[15] F. Alemanno, M. Centonze, and **A. Fachechi**, "Interpolating between boolean and extremely high noisy patterns through minimal dense associative memories," *Journal of Physics A: Mathematical and Theoretical*, vol. 53, no. 7, p. 074 001, 2020.

[16] E. Agliari, F. Alemanno, A. Barra, and **A. Fachechi**, "Dreaming neural networks: Rigorous results," *Journal of Statistical Mechanics: Theory and Experiment*, vol. 2019, no. 8, p. 083 503, 2019.

[17] E. Agliari, F. Alemanno, A. Barra, and **A. Fachechi**, "On the Marchenko–Pastur law in analog bipartite spin-glasses," *Journal of Physics A: Mathematical and Theoretical*, vol. 52, no. 25, p. 254 002, 2019.

[18] **A. Fachechi**, E. Agliari, and A. Barra, "Dreaming neural networks: Forgetting spurious memories and reinforcing pure ones," *Neural Networks*, vol. 112, pp. 24–40, 2019.

[19] E. Alfinito, A. Barra, M. Beccaria, **A. Fachechi**, and G. Macorini, "An evolutionary game model for behavioral gambit of loyalists: Global awareness and risk-aversion," *Europhysics Letters*, vol. 121, no. 3, p. 38 001, 2018.

[20] A. Barra, M. Beccaria, and **A. Fachechi**, "A new mechanical approach to handle generalized Hopfield neural networks," *Neural Networks*, vol. 106, pp. 205–222, 2018.

[21] **A. Fachechi**, G. Macorini, and M. Beccaria, "Chiral trace relations in supersymmetric gauge theories," *Theoretical and Mathematical Physics*, vol. 196, no. 3, pp. 1282–1293, 2018.

[22] E. Alfinito, M. Beccaria, **A. Fachechi**, and G. Macorini, "Reactive immunization on complex networks," *Europhysics Letters*, vol. 117, no. 1, p. 18 002, 2017.

[23] M. Beccaria, **A. Fachechi**, and G. Macorini, "Chiral trace relations in Ω-deformed $\mathcal{N} = 2$ theories," *Journal of High Energy Physics*, vol. 2017, no. 5, pp. 1–37, 2017.

[24] M. Beccaria, **A. Fachechi**, and G. Macorini, "On the cusp anomalous dimension in the ladder limit of $\mathcal{N} = 4$ sym," *Journal of High Energy Physics*, vol. 2016, no. 6, pp. 1–21, 2016.

[25] M. Beccaria, **A. Fachechi**, and G. Macorini, "Virasoro vacuum block at next-to-leading order in the heavy-light limit," *Journal of High Energy Physics*, vol. 2016, no. 2, pp. 1–22, 2016.

[26] M. Beccaria, **A. Fachechi**, G. Macorini, and L. Martina, "Exact partition functions for $\Omega-$deformed $\mathcal{N} = 2$ theories with $N_f = 4$ flavours," *Journal of High Energy Physics*, vol. 2016, no. 12, pp. 1–41, 2016.

Conference Proceedings

[1] **A. Fachechi**, G. Macorini, and M. Beccaria, "Chiral trace relations in Ω-deformed $\mathcal{N} = 2$ theories," in *Journal of Physics: Conference Series*, IOP Publishing, vol. 965, 2018, p. 012 013.

[2] E. Alfinito, M. Beccaria, **A. Fachechi**, G. Macorini, *et al.*, "Probing complexity with epidemics: A new reactive immunization strategy.," in *COMPLEXIS*, 2017, pp. 116–123.

Selected talks to conferences and invited talks

2024
- *A Hopfield-like picture to address generalization and overfitting,* Mathematics for Artificial Intelligence and Machine Learning, University Bocconi of Milano.

2023
- *Dreaming Neural Networks: pushing retrieval/learning capabilities to the limit by "sleeping" mechanism*, Physics-informed machine learning workshop, Alan Turing Institute.
- *Machine Learning from a spin-glass theory perspective*, Stochastic Models for Complex Systems, Department of Mathematics E. De Giorgi, Unisalento.
- *Retrieving, unlearning and learning: there and back again*, Department of Physics, Sapienza University of Rome.

2022
- *Dreaming Neural Networks: pushing retrieval/learning capabilities to the limit by "sleeping" mechanism*, Matematica per l'Intelligenza Artificiale e il Machine Learning - Giovani ricercatori, Politecnico di Torino.
- *PDE/Statistical Mechanics relation: from p-spin ferromagnets to dense associative memories*, Department of Mathematics, Sapienza University of Rome.
- *Dreaming Neural Networks: pushing retrieval/learning capabilities to the limit by "sleeping" mechanism*, Unconventional Computation Workshop, Swansea University.

2021
- *Dreaming Neural Networks: dal richiamo automatico all'apprendimento*, Divulgazioni Notturne di Fisica Matematica, online talk for GNFM (Gruppo Nazionale della Fisica Matematica).

2018
- *Sleeping in Hopfield neural networks: some recent results*, Department of Mathematics, King's College London.

2017
- *Chiral trace relations in Ω-deformed $\mathcal{N} = 2$ theories*, XXVth International Conference on Integrable Systems and Quantum symmetries, Czech Technical University Prague.
- *Chiral trace relations in Ω-deformed $\mathcal{N} = 2$ theories*, Physics and Mathematics of Nonlinear Phenomena – "50 years of IST", Unisalento.