

Francesco Cagnetta

Theoretical and Scientific Data Science group

Scuola Internazionale Superiore di Studi Avanzati
di Trieste (SISSA)

ORCID: <https://orcid.org/0000-0002-8302-431X>

Email: francesco.cagnetta@sissa.it

Postdoctoral Experience

1/10/2024-30/9/2026 **Marie Skłodowska-Curie fellowship** on the Correlation-Oriented Representation Learning (CORaL) project, aimed at studying the relationship between data correlations and the hidden representations of deep neural networks. Hosted by the Theoretical and Scientific Data Science group at Scuola Internazionale Superiore di Studi Avanzati (SISSA).

1/9/2020-30/9/2024 **Postdoctoral researcher** at École Polytechnique Fédérale de Lausanne (EPFL) in the Physics of Complex Systems Laboratory (PCSL) led by Matthieu Wyart.

I am currently working on understanding the structure of natural data, such as images and text. I particularly focus on hierarchical latent structures, their impact on measurable data statistics and their interplay with the layered structure of deep learning models.

Education

PhD Physics, on “Active interfaces, a universal approach”, University of Edinburgh, supervised by Martin R. Evans and Davide Marenduzzo, 1/9/2016-18/5/2020.

M.Sc. Physics *cum laude*, on “Large deviations of self-propelled particles”, University of Bari, supervised by Giuseppe Gonnella, 1/9/2013-31/8/2016.

B.Sc. Physics *cum laude*, on “The anomalous diffusion in the chaotic pendulum”, University of Bari, supervised by Giuseppe Gonnella and Stefano Ruffo, 1/9/2010-31/8/2013.

Awards & Grants

Marie Skłodowska-Curie Action (MSCA) grant for the Correlation-Oriented Representation Learning (CORaL) project, 2024.

Ref. [3] selected as *Editor's suggestion* in Phys. Rev. Lett. with a dedicated viewpoint article.

SFC Higgs International Studentship, 2016-2020.

young researcher grant from GSSI, 2015.

Teaching Experience

Lecturer. ‘Information theory’ module of Statistical Physics 3, year 4 course at EPFL (2023).

Lecturer. ‘Self-Avoiding Walks and polymers’ module of Statistical Physics 3, year 4 course at EPFL (2022).

Teaching Assistant. Statistical Mechanics 3, year 4 course at EPFL (2020, 2021, 2022, 2023).

Teaching Assistant. Methods of Theoretical Physics, year 3 course at the University of Edinburgh (2019).

Teaching Assistant. Advanced Statistical Physics, year 5 course at the University of Edinburgh (2018).

Teaching Assistant. General Relativity, year 5 course at the University of Edinburgh (2018).

Teaching Assistant. Advanced Statistical Physics, year 5 course at the University of Edinburgh (2017).

Teaching Assistant. Statistical Mechanics, year 3 course at the University of Edinburgh (2017).

Supervising Experience

Supervision of E. Hernández Moreno's (Tecnológico de Monterrey) **Research internship** (Fall 2025).

Supervision of L. Hammache's (ENS de Lyon) **Research internship** (Spring 2025).

Supervision of E. Mettraux's **Specialisation** project at EPFL (2024).

Co-supervision of G. Zhang's **MSc thesis** projects at EPFL (2023).

Co-supervision of N. Sandgathe and A. Salvatore **Research semester** projects at EPFL (2022).

Co-supervision of A. Favero's **Research internship** at EPFL (2020-2021), led to [11].

Co-supervision of M. Semeraro's **MSc thesis** project at the University of Bari (2020), led to [10].

Co-supervision of P. Chiarantoni's **MSc thesis** project at the University of Bari (2019), led to [9].

Scientific Organization

Workshop on "Fundamental principles of Large Language Models", Lausanne, May 2026. Organizer.

EurIPS2025 Workshop "Principles of Generative Modeling (PriGM)", Copenhagen, Dec 2025. Organizer.

Webinars of the "Physics of Learning and Neural Computation" collaboration, Online at www.physicsoflearning.org, Aug 2024-Ongoing. Organiser.

IV Workshop "Interdisciplinary Challenges: from Nonequilibrium Physics to Life Sciences", Rome, Apr 2023. Organiser.

FLAIR (Fundamentals of Learning and Artificial Intelligence) tutorial meetings, EPFL, Sep 2022-Sep 2024. Organiser.

SPOC+idePHICS+PCSL joint group meetings, EPFL, Sep 2020-Sep 2022. Organiser.

Statistical Physics and Complexity reading group, University of Edinburgh, 2019. Organiser.

Professional Development

Annual meeting of the Simons Collaboration on "the physics of learning and neural computation", Stanford, Nov 2025.

Invited researcher at the "Deep Learning from the Perspective of Physics and Neuroscience" programme, Kavli Institute for Theoretical Physics, Santa Barbara, Dec 2023.

Summer School on "Statistical Physics & Machine learning", École de Physique des Houches, Aug 2022.

Swiss Equivariant Learning Workshop, EPFL, Lausanne, Jul 2022.

Workshop "Youth in High-Dimensions: Recent Progress in Machine Learning, High-Dimensional Statistics and Inference", ITCP, trieste, Jun 2022.

Annual meeting of the Simons Collaboration on "Cracking the glass problem", Venice, Nov 2021.

Workshop "Universality in Interacting Particle Systems", UoC Forum "Classical and quantum dynamics of interacting particle systems", Cologne, Sep 2019.

Workshop "Field theories of Active and Driven matter", Higgs centre for theoretical Physics, Edinburgh, May 2019.

Erice Workshop on Self-Organization in Active Matter: from Colloids to Cells, Erice, Oct 2018.

Workshop on teaching and learning statistical physics, Montepulciano, Apr 2018.

TAU-ESPCI International Winter School on Active Matter, Tel Aviv University, Jan 2018.

Bangalore School on Statistical Physics VIII, ICTS Bengaluru, Summer 2017.

Non Standard Transport workshop, Gran Sasso Science Institute, Summer 2015.

Publications (* denotes co-first authorship)

- [24]] F. Cagnetta, A. Favero, A. Sclocchi, M. Wyart, *Scaling Laws and Representation Learning in Simple Hierarchical Languages: Transformers vs. Convolutional Architectures*, to appear in PRE special issue on Statistical Physics and Machine Learning.
- [23]] A. Favero, A. Sclocchi, F. Cagnetta, P. Frossard, M. Wyart, *How compositional generalization and creativity improve as diffusion models are trained*, ICML 2025.
- [22]] F. Cagnetta, H. Kang, M. Wyart, *Learning curves theory for hierarchically compositional data with power-law distributed features*, ICML 2025.
- [21]] H. Kang, F. Cagnetta, M. Wyart, *How rare events shape the learning curves of hierarchical data*. NeurIPS 2024 Workshop on Scientific Methods for Understanding Deep Learning.
- [20]] F. Cagnetta, M. Wyart, *Token-token correlations predict the scaling of the test loss with the number of input tokens*. NeurIPS 2024 Workshop on Scientific Methods for Understanding Deep Learning.
- [19]] F. Cagnetta, M. Wyart, *Towards a theory of how the structure of language is acquired by deep neural networks*, NeurIPS 2024.
- [18]] F. Cagnetta*, L. Petrini*, U. M. Tomasini, A. Favero, M. Wyart, *How Deep Neural Networks Learn Compositional Data: The Random Hierarchy Model*, arXiv:2307.02129 (accepted on Phys. Rev. X).
- [17]] F. Cagnetta, D. Oliveira, M. Sabanayagam, N. Tsilivis, *Kernels, Data & Physics*, to appear in J. Stat. Mech. Lecture Notes.
- [16]] U. M. Tomasini, L. Petrini, F. Cagnetta, M. Wyart, *how deep convolutional neural networks lose spatial information with training*, arXiv:2210.01506.
- [15]] F. Cagnetta, A. Favero, M. Wyart, *What can be learnt with wide convolutional neural networks?*, ICML 2023.
- [14]] L. Petrini*, F. Cagnetta*, E. Vanden-Eijnden, M. Wyart, *Learning sparse features can lead to overfitting in neural networks*, NeurIPS 2022.
- [13]] F. Cagnetta*, V. Škultéty*, M. R. Evans, D. Marenduzzo, *Renormalization group study of the dynamics of active membranes: Universality classes and scaling laws*, Phys. Rev. E 105 (2022) 104610.
- [12]] F. Cagnetta*, V. Škultéty*, M. R. Evans, D. Marenduzzo, *Universal properties of active membranes*, Phys. Rev. E 105 (2022) L012604.
- [11]] A. Favero*, F. Cagnetta*, M. Wyart, *Locality defeats the curse of dimensionality in convolutional teacher-student scenarios*, NeurIPS 2021.
- [10]] M. Semeraro, A. Suma, I. Petrelli, F. Cagnetta, G. Gonnella, *Work fluctuations in the active Ornstein-Uhlenbeck Particle model*, J. Stat. Mech. Theory Exp. (2021) 123202.
- [9]] P. Chiarantoni, F. Cagnetta, F. Corberi, G. Gonnella, A. Suma, *Work fluctuations of self-propelled particles in the phase separated state*, J. Phys. A: Math. Theo. 53 (2020) 36LT02.
- [8]] F. Cagnetta, M. R. Evans, D. Marenduzzo, *Kinetic roughening in active interfaces*, EPJ WoC 230 (2020) 00001.
- [7]] F. Cagnetta, D. Michieletto, D. Marenduzzo, *A nonequilibrium strategy for fast target search on the genome*, Phys. Rev. Lett. 124, (2020) 198101.
- [6]] F. Cagnetta*, E. Mallmin*, *Efficiency of one-dimensional active transport conditioned on motility*, Phys. Rev. E 101 (2020) 022130.

- [5] F. Cagnetta, M. R. Evans, *Inviscid limit of the active interface equations*, J. Stat. Mech. Theory Exp. (2019) 113206.
- [4] F. Cagnetta, M. R. Evans, D. Marenduzzo, *Statistical mechanics of a single active slider on a fluctuating interface*, Phys. Rev. E 99 (2019) 042124.
- [3] F. Cagnetta, M. R. Evans, D. Marenduzzo, *Active interface growth and pattern formation*, Phys. Rev. Lett. 120 (2018) 258001—editor’s suggestion & featured in Physics.
- [2] F. Cagnetta, F. Corberi, G. Gonnella, A. Suma, *Large fluctuations and dynamic phase transition in self-propelled particles systems*, Phys. Rev. Lett. 119 (2017) 158002.
- [1] F. Cagnetta, G. Gonnella, A. Mossa and S. Ruffo, *Strong anomalous diffusion in the phase of a chaotic pendulum*, Europhys. Lett. 111 (2015) 10002.

Talks and Posters

“A model-based approach to the theory of Language Modelling” Invited Talk. Studying Artificial Intelligence at Scale Workshop, Perimeter Institute for Theoretical Physics, Waterloo, October 2025.

“Towards a theory of how the structure of language is acquired by deep neural networks” Invited Talk. Leman-Th 2025 Workshop on Machine Learning & Neural Network Theory, EPFL, Lausanne, May 2025.

“Towards a theory of how the structure of language is acquired by deep neural networks” Invited Talk. Non-equilibrium thermodynamics: from chemical reactions to machine learning Workshop, Higgs centre for Theoretical Physics, Edinburgh, April 2025.

“Towards a theory of how the structure of language is acquired by deep neural networks” Invited Talk. Statistical Physics meets Machine Learning Focus Session, APS Global Physics Summit, Anaheim, March 2025.

“Towards a theory of how the structure of language is acquired by deep neural networks” Poster. neurIPS 2024, Vancouver, December 2024.

“Predicting Scaling Laws in Self-Supervised Learning via Data Correlations” Invited Talk. From Machine-Learning Theory to Driven Complex Systems and back Workshop, CECAM-EPFL, Lausanne, May 2024.

“Learning Hierarchical Compositionality with Deep CNNs: Insights from a Random Hierarchy Model” Invited Talk. Analytical Connectionism Workshop, Gatsby Computational Neuroscience Unit, London, September 2023.

“Learning Hierarchical Compositionality with Deep CNNs: Insights from a Random Hierarchy Model” Invited Talk. 9th International Discussion Meeting on Relaxations in Complex Systems, Tokyo, August 2023.

“Learning Hierarchical Compositionality with Deep CNNs: Insights from a Random Hierarchy Model” Contributed Talk. Statphys28, Tokyo, August 2023.

“What can be learnt with wide convolutional neural networks?” Poster. ICML 2023.

“Learning Hierarchical Compositionality with Deep CNNs: Insights from a Random Hierarchy Model” Invited Talk. Youth in High-Dimensions Workshop, ICTP, Trieste, June 2023.

“Learning sparse features can lead to overfitting in neural networks” Poster. NeurIPS 2022 (online).

“Exploring the compositional structure of data with deep convolutional kernels” Contributed Talk. 4th IMA Conference on The Mathematical Challenges of Big Data, Oxford, October 2022.

“Structure beyond symmetry: locality and compositionality in deep convolutional networks” Invited Talk. Swiss Equivariant Learning Workshop, EPFL, July 2022.

“How deep convolutional networks learn hierarchical tasks” Contributed talk. AI4Science day, EPFL, June 2022.

“Exploring the compositional structure of data with deep convolutional kernels” Poster. Youth in High-Dimensions Workshop, ICTP, Trieste, June 2022.

"A scaling theory of learning for structured data" Invited Talk. Physics of Life Summer School "Interdisciplinary Challenges: from Non-equilibrium Physics to Life Sciences", Edinburgh, April 2022.

"Locality defeats the curse of dimensionality in convolutional teacher-student scenarios" Poster. NeurIPS 2021 (online).

"Beating the curse of dimensionality via locality: a lesson from convolutional kernels" Poster. Workshop "On Future Synergies for Stochastic and Learning Algorithms", CIRM Marseille, September 2021.

"Efficiency of one-dimensional active transport conditioned on motility" Contributed Talk. ESI Workshop on "Interdisciplinary Challenges in Nonequilibrium Physics", Vienna, April 2021 (Online).

"Emergent interactions in conditioned processes: a route to smart matter?" Invited Talk. Institute of Physics, EPFL Lausanne, February 2020.

"Emergent interactions in conditioned processes: a route to smart matter?" Invited Talk. Departamento de Física de la Materia Condensada, University of Barcelona, November 2019.

"Active interfaces: a universal approach" Contributed Talk. Italian national conference on the physics of matter, Catania, October 2019.

"Active interfaces: a universal approach" Contributed Talk. StatPhys27, Buenos Aires, July 2019.

"Surfing & Roughening: physics of a toy active interface" Invited Talk. Department of Physics, University of Aberdeen, October 2018. Erice Workshop on Self-Organization in Active Matter: from Colloids to Cells, Erice, October 2018.

"Pattern formation on active interfaces" Contributed Talk. Erice Workshop on Self-Organization in Active Matter: from Colloids to Cells, Erice, October 2018.

"Universality of the KPZ equation" Contributed Talk. Workshop on Teaching and Learning Statistical Physics, Montepulciano, April 2018.

"Large deviations of self-propelled particles" Poster. 1st BioForPhys conference, Barcelona, January 2017.