Filippo Vicentini

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Address
15 Avenue de Jurigoz,
1006, Lausanne
Switzerland

Birth
Born in Padova, Italy
1^{st} August 1992

Skills
Machine Learning
Quantum Computing
Quantum Machine L.
VQE
Scientific Progr.
Differentiable Progr.
Neural Networks
Natural Gradient
Python
Jax
Julia
LLVM
C++
Matlab
Parallel-Computing
(S)DE solvers

Filippo Vicentini, Ph.D.

Computational Quantum Physicist

In short: I am a theoretical physicist researching machine-learning algorithms to solve quantum-mechanical problems. My primary research involves using neural-networks and similar techniques to simulate non-equilibrium quantum systems or to perform quantum state reconstruction. This makes me knowledgeable topics such as High Performance Computing, compilers, second order optimisation techniques and symmetries. My secondary axis exploits my knowledge on classical neural-networks to develop variational quantum algorithms for time-evolution or higher order QML optimisation. I lead a collaboration developing open-source scientific software connected to numerical quantum physics.

Work

Sept 2020 - now: ***Postdoctoral Researcher*****, Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland**

- Lead developer for NetKet, an open-source project on machine-learning techniques for quantum physics
- Research on symmetry-encoding neural-networks for non-equilibrium;
- Development of Variational Quantum Algorithms for time evolution;
- Teaching assistant and advisor to several doctoral students.

May-Sep 2020: ***Visiting Research Scholar*****, Flatiron Institute, New York**
Remote position due to COVID pandemic. Development of Neural Network simulation methods for open quantum systems and DFT methods for dissipative light-matter systems.

Jan-Mar 2020: ***Postdoctoral Researcher*****, Universitè de Paris, France**

Education

2016 - 2019: ***Ph.D. in Physics*****, Universitè de Paris, France**

- Laboratoire Matériaux et Phénomènes Quantiques
- **Thesis:** Stochastic and Neural Network methods for many-body open quantum systems (defended December 11, 2019)

  Advisor: Prof. Cristiano Ciuti

2014 - 2016: ***M.Sc. in Physics*****, Università di Padova, Italy**

- **2015-2016: Exchange Student, Ecole Normale de Paris, France**
  - **Thesis:** Single Spin Manipulation in a cQED architecture **(110/110 cum Laude)**

    Advisor: Prof. Takis Kontos (**LPA-ENS, Paris**)

April 2013: ***Masterclass in Plasma Physics*****, TU/Eindhoven, NL**

- **Final Project:** Hyperfine Spectroscopy of RB Atoms

2011 - 2014: ***B.Sc. in Physics*****, Università di Padova, Italy**

- **Thesis:** Variational study of a 1D supersolid model **(104/110)**

Prizes

ATOS Joseph Fourier Award 2019

- **Special Jury Prize for Artificial Intelligence** - awarded for my research bridging machine learning and quantum physics. For more info see (press release) and (link to University communication).

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Organised Conferences

Bernoulli Workshop: Variational Learning Quantum Matter

- ***4-8 July 2022*** Workshop at the intersection between classical and quantum variational algorithms to study quantum many-body systems. The workshop is interdisciplinary and will feature some high profile speakers from Academia as well as Industry (IBM, Google, Xanadu...). I have **independently** applied for $\approx 75k$CHF funding from 2 different entities. I am co-organising the workshop with another Postodctoral fellow at EPFL, and no senior reseearchers are involved in the organisation. Conference website: https://mlquantum.org

Articles

10 Anna Dawid, [...], F. Vicentini et Al., Modern applications of machine learning in quantum sciences (Lecture notes), arXiv:2204.04198

9 S. Barison, F. Vicentini, I.Cirac and G. Carleo, Variational dynamics as a ground-state problem on a quantum computer, arXiv:2204.03454

8 F. Vicentini, D. Hoffman et Al. NetKet 3: Machine Learning Toolbox for Many-Body Quantum Systems, arXiv:2112.10526, Submitted to SciPost Codebases

7 D. Hafner and F. Vicentini, mpi4jax: Zero-copy MPI communication of JAX arrays, Journal of Open Source Software 6, 3419 (2021)

6 S. Barison F. Vicentini and G. Carleo, An efficient quantum algorithm for the time evolution of parameterized circuits, Quantum 5, 512 (2021)

5 G.Carleo, [...] F. Vicentini et Al., NetKet: A Machine Learning Toolkit for Many-Body Quantum Systems, SoftwareX 100311 (2019)

4 V. Goblot, B. Rauer, F. Vicentini, A. Le Boité, E. Galopin, A. Lemaitre, L. Le Gratiet, A. Harouri, I. Sagnes, S. Ravets, C. Ciuti, A. Amo, J. Bloch, Discrete nonlinear domains for polariton fluids in a flat band, Phys. Rev. Lett **123** (11) 113901 (2019)

3 F. Vicentini, A. Biella, N. Regnault and C. Ciuti, Variational neural network ansatz for steady states in open quantum systems, Phys. Rev. Lett. **122** (25) 250503 (2019)

2 F. Vicentini, F. Minganti, A. Biella , G. Orso and C. Ciuti, Optimal stochastic unraveling of disordered open quantum systems: Application to driven-dissipative photonics lattices, Phys. Rev. A **99** (1) 032115 (2019)

1 F. Vicentini, F. Minganti, R. Rota, G. Orso and C. Ciuti, Critical slowing down in driven-dissipative Bose-Hubbard lattices, Phys. Rev. A **97** (1) 013853 (2018)

Unreleased Preprints

12 D. Wu, R. Rossi, F. Vicentini and G. Carleo, From Tensor Network Quantum States to Tensorial Recurrent Neural Networks, ...

11 F. Vicentini R. Rossi and G. Carleo, Deep Positive Definite Neural Networks for Neural Density Matrices, ...

Talks and Schools

12. April 2022: Invited lecturer at doctoral school "**Toulouse Summer School on Machine Learning for Quantum-Many Body Physics**", Toulouse, France
11. March 2022: Contributed talk "Neural Network Ansatz for Finite Temperature" at APS March Meeting, Chicago, USA

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Neural Networks
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Python
Jax
Julia
LLVM
C++
Matlab
Parallel-Computing
(S)DE solvers

10. November 2021-February 2021: Contract Lecturer at doctoral course "**Introduction to Deep Learning**", Como, Italy
9. September 2021: Invited Lecturer at Doctoral school "**Machine-Learning for Quantum Physics**", Warsaw, Poland
8. January 2021: Lecturer at "**Machine Learning for Condensed Matter**" conference, ICTP Trieste, Italy
7. June 2020: Invited talk at **Machine Learning for Quantum Simulation** virtual conference hosted by Flatiron Institute, New York
6. July 2019: Contributed talk at **Congres General de la Societé Francaise de Physique**, Nantes, France
5. June 2019: *Machine Learning for Physical application*, talk at UFR Physique, Paris 7 University
4. May 2019: Contributed talk at **Machine Learning for Quantum Technologies** conference, Max Planck for Quantum Optics, Erlangen, France
3. March 2019: Invited seminar at **ENS Lyon**, Lyon, France
2. March 2019: Contributed talk at **Artificial Intelligence and Physics Conference** conference, Paris, France
1. January 2018: Invited talk at **Numerical Methods for Quantum Optics** conference, Max Planck for Quantum Physics, Munich, Germany

Posters

6. February 2019: **Machine Learning for quantum many body physics**, Kavli Institute of Theoretical Physics, Santa Barbara, USA
5. June 2018: **Quantum Fluids of Light and Matter**, Les Houches Summer School, France
4. June 2018: **Current trends in open and nonequilibrium quantum optical systems**, Max Planck Institute for Quantum Optics, Erlangen, Germany
3. November 2017: **Quantum Simulation Conference**, Paris, France
2. September 2017 **Recent Trends in Light and Matter Interaction Summer School**, Lausanne, Switzerland
1. May 2017 **Quantum Fluids of Light and Matter Conference**, Cargese, France

Supervised Students

6-7. (January-*June* 2022) Co-Supervision of 2 **M1 Master students** for their internship projects
5. (February-July 2021) Co-Supervised **1 M2 Master** student (Louis Pezon) from another group for his 6+ months internship project.
4. (2021-*ongoing*) Co-Supervised **1 M2 Master** student (Clemens Giuliani) for his 6 months internship project. He is **now a Ph.D. Student** whom I co-supervise on his project about ML methods for Quantum Dynamics.
3. (2021-*ongoing*) Co-Supervision of Ph.D. Student **Stefano Barison** working on Hybrid Quantum Algorithms
1-2. (March-June 2020) tutored two M2 internship students at the C12 Startup (LPA-ENS) on Machine Learning techniques and device modelling for Quantum Optical Control.

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Python
Jax
Julia
LLVM
C++
Matlab
Parallel-Computing
(S)DE solvers

Professional Skills

Programming

- I mainly code in **Python** (Jax) or **Julia**. I'm familiar with the tech stach down to LLVM and MLIR. I'm also familiar with **Matlab**.
- I used to code in **C++14** and parallelize code with threads and MPI. Nowdays I'd rather work in **Julia** unless necessary.
- I am lead developer of the **NetKet** collaboration, an open-source project in Python with 12 active contributors, and organize the work of the whole collaboration. I wrote some high-profile code for Jax.
- I am a contributor to some **Julia** open source projects. Check my GitHub if interested.

[M]ath, [P]hysics and [N]eural-Networks

P I worked daily on **Open Quantum System**, and extensively studied their mapping to **Stochastic Markov Equations**. I studied Out-Of-Equilibiurm Phase Transitions. I am familiar with **Quantum MonteCarlo** Methods and with **MPS/MPO** solvers.

P I have developed variational quantum algorithms (p-VQD) to compress the time-evolution of a quantum system, inspired by higher-order techniques such as Natural Gradient.

M I have a very good knowledge on numerically solving Stocastic Differential Equations (**SDE**).

N I have worked extensively with Machine Learning frameworks and Neural Networks in uncommon use-cases, mainly higher-order optimisation methods and generative models.

Languages

- **Italian:** Mothertongue
- **English:** (C1 in 2011) Fluent, used daily in work and life
- **French:** (B2) Fluent, used daily in work and life

References

Prof. Giuseppe **Carleo**, EPFL (Lausanne) *Collaborator, Postdoc Advisor*
giuseppe.carleo@epfl.ch

Prof. Cristiano **Ciuti**, MPQ (Paris) *Ph.D. Advisor*
cristiano.ciuti@univ-paris-diderot.fr

Prof. Vincenzo **Savona**, EPFL (Lausanne) *Collaborator*
vincenzo.savona@epfl.ch

Prof. Fabien **Alet**, CNRS (Toulouse) *Worked with him during the Toulouse Summer School*
alet@irsamc.ups-tlse.fr

Addendum to the Curriculum Vitae

Filippo Vicentini
École Polytechnique Fédérale de Lausanne (EPFL), Institute of Physics,
CH-1015 Lausanne, Switzerland

1 Overview of my previous research

I started my career by investigating several aspects of many-body open quantum systems inspired by quantum-optics experiments. I have studied in detail the emergence of first-order phase transitions in this class of systems by means of finite-size scaling arguments coupled to heavy numerical simulations [1]. To investigate disorder I proposed an efficient monte-carlo scheme to couple stochastic trajectories methods to disorder averages [2], and some of those ideas where used to provide theoretical support to an experimental collaboration with the group of Jaqueline Bloch at C2N [3]. Towards the end of my Ph.D. I proposed a scheme to use Machine-Learning methods to solve open quantum systems, and contributed an implementation to the open-source NetKet software [4, 5].

During the 2020 pandemic I did some consulting for the C12 quantum startup in paris with whom I was involved during my M2 internship, which motivated me to start working on quantum algorithms as well.

Since I became a post-doc at EPFL in september 2020, I have soon got heavily involved with the NetKet project, and I spent a large part of my first year overhauling it and building a community around it. I also kept investigating how to improve ML methods for open quantum systems, mainly focusing on the encoding of the density matrix [6]. A spin off of this project, carried out in the forefront by a PhD student I co-supervise, has been an investigation into the mapping between Recurrent Neural Networks and Matrix Product States [7]. Finally, I have recently started investigating kernel methods such as the Neural Tangent Kernel in order to develop an algorithm that has a more controllable error, in particular in relation with dynamics. I'm still in the early stages of this research, but if it will succeed it will be an elegant alternative to NQS.

While I have not been directly involved in efforts going on inside of the group relating to NQS encodings of continuous and/or fermionic systems, I assisted most Ph.D. students in their implementation and contribution to NetKet [5, 8], which gave me a fairly deep insight in the way NQS algorithms work in such domains where I am not directly working. In particular, fermionic systems with a finite number of orbitals and continuous bosonic systems.

In parallel, I have also been involved in an effort developing quantum algorithms for simulating the quantum dynamics on a quantum computer. The first such algorithm, the p-VQD [9] has been very well received and I am involved in a collaboration with IBM to run this algorithm in one of their most advanced machines. More recently, we attempted to recast the dynamics problem into a ground-state problem to devise a new quantum algorithm [10].

In December 2021 I applied for funding to organise a workshop at the intersection of Classical and Quantum Variational Algorithms. I was able to secure about ~ 75 thousand CHF from the Bernoulli center for Fundamental Studies and EPFL's Center for Quantum Science and Engineering through

grants reserved for junior, non-permanent researchers. The workshop, titled "Variational Learning of Quantum Matter" will run for a week at the beginning of July 2022, and together with my co-organiser Dr. Jannes Nys we have secured the partecipation of several figures from different fields, such as Chemistry and Mathematics, as well as partecipants from industry partners such as IBM, Google and Xanadu. I believe this workshop reflects very well the direction I am following for my research.

Management experience: During my 18 months at EPFL I have been directly supervising 2 PhD students in their research as well as 4 Master Students. I have also supervised other Ph.D. students together with other contributors to the NetKet project in order to implement the large set of features that we wanted to include in the release of the new version.

2 Teaching Experience

In this section I list the relevant teaching experiences.

2.1 Frontal classes

This list is in reverse cronological order.

- *Toulouse Summer School on Machine Learning for Quantum-Many Body Physics* (April 2022). I have given 4 hours of *tutorials* on machine-learning tools to model quantum many-body systems to Ph.D.-level partecipants and a research seminar. I have taken part in the scheduling of the sessions related to Neural Quantum States and proposed other speakers and lecturers. I have designed a set of Python notebooks for the practicals, and they can be accessed at https://github.com/PhilipVinc/Lectures. (Website: https://mlqmb.sciencesconf.org Reference: Dir. Rech. Fabien Alet (alet@irsamc.ups-tlse.fr));

- *Introduction to Deep Learning* (Università dell'Insubria, Como (IT), (November 2021-February 2022). I was a **contract lecturer** for this 16-hours course aimed at Ph.D. level students from Physics, Mathematics, Computer Science and Economy students. I have co-designed the class syllabus with the other lecturer, prepared the teaching material, taught the 8-hours of practicals (TD) and prepared the final evaluation exam. The course started with an introduction to Machine-Learning (Automatic Differentiation, Representation Theorems, Supervised and Unsupervised learning) together with an hands-on introduction to programming tools (PyTorch and Jax). We then covered generative models and autoregressive Neural Networks, Policy Gradients and Reinforcement Learning and finally some notions of Machine Learning tools for Quantum Physics. (Reference: Prof. Giuliano Benenti (giuliano.benenti@uninsubria.it));

- *Warsaw Summer School: Machine-Learning in Quantum Physics and Chemistry* (September 2021). School aimed at 2$^{\text{nd}}$ year master/first year Ph.D. students. I have taught a total of 4 hours of classes and hands on. (Website: https://szkoly.idub.uw.edu.pl/) This also resulted in the writing and editing of Chapters 2 and 5 of the Lecture Notes "Modern applications of machine learning in quantum sciences" [11];

- *The Hitchhiker's Guide to Condensed Matter and Statistical Physics: Machine Learning for Condensed Matter* ICTP Virtual School (January 2021). School aimed at 2$^{\text{nd}}$ year master/first year

Ph.D. students. I have taught 1 introductory class to Machine-Learning methods for condensed matter, and I have been a tutor for the hands-on. (Website: https://indico.ictp.it/event/9471/);

- *Application of Machine Learning to Physics* M2/Ph.D. level elective for EPFL students (December 2020). I have been a tutor for the 4-hours module on Neural Quantum States. (Referent: Prof. Giuseppe Carleo (giuseppe.carleo@epfl.ch));

2.2 Teaching Experience: Student Mentoring

This list is in reverse chronological order.

- **Supervision of M1 internship student** Pauline de Schoulepnikoff (*February 2022-ongoing)* on the project **"Combining Natural gradient descent with advanced gradient optimisers for frustrated ground state optimisation"**.
- **Co-supervision of M1 internship student** Alessandro Sinibaldi (*February 2022-ongoing)* on the project **"Implicit Solver methods for Variational Quantum Dynamics"**.
- **Co-supervision of Ph.D. student** Clemens Giuliani *(September 2021-Ongoing)* on the project **"Development of novel machine-learning methods for variational quantum dynamics"**.
- **Co-supervision of research intern** in Vincenzo Savona's group Louis Pezon *(February-July 2021)* on the project **"Neural Quantum Trajectory methods for solving the stochastic schroedinger's equation"**.
- **Co-supervision of Ph.D. student** Stefano Barison *(September 2020-Ongoing)* on the project **"Variational Quantum Algorithms for the simulation of Quantum dynamics"**.
- **Co-supervision of M2 internship student** Clemens Giuliani *(February-June 2021)* on the project **"Variational methods for simulating quantum circuits"**.
- **External advising** of two M2 internship students from the ICFP Master during theyr research at the Startup C12 (ENS-LPA) in march-july 2020. They were working on modelling and control of a Spin-based Qubit.

2.3 Commentary

My teaching experience has been focused around introductory classes to Machine-Learning, several TD/Seminars about Neural Network Quantum States methods and introductions to programming tools like PyTorch, Jax and NetKet. The most formative experience for me was the *Introduction to Deep Learning* course in Como for which I was a contract lecturer, when for the first time I had to teach such concepts not only to Physicists and Mathematicians, who have a very strong linear algebra knowledge, but also to Economy students, who have a different backgorund.

Among the students mentored, I feel particularly proud about Clemens. He was a computer science M2 student from ETH who joined Prof. Carleo's group in February 2021 for his master internship. Due to his different background he lacked knowledge about physics and the intuition that comes with it about concepts such as phase transitions, correlations and entanglement. Working with him was particularly insightful as to how non-physicists think about such concepts and how best to introduce

them to someone who was never exposed before in a condensed manner. Clemens later joined the group for his PhD.

I also am particularly pleased by the fact that the PI of another group, Vincenzo Savona, reached out to me around the same time to supervise one of his master students in a joint project between his group, specialised in open quantum systems, and our group, focused on Machine Learning.

References

[1] **F. V.**, Fabrizio Minganti, Riccardo Rota, Giuliano Orso, and Cristiano Ciuti. "Critical slowing down in driven-dissipative Bose-Hubbard lattices". In: *Physical Review A* 97.1 (Jan. 2018). DOI: 10.1103/physreva.97.013853.

[2] **F. V.**, Fabrizio Minganti, Alberto Biella, Giuliano Orso, and Cristiano Ciuti. "Optimal stochastic unraveling of disordered open quantum systems: Application to driven-dissipative photonic lattices". In: *Physical Review A* 99.3 (Mar. 2019). DOI: 10.1103/physreva.99.032115.

[3] V. Goblot, ..., and **F. V.** et Al. "Nonlinear Polariton Fluids in a Flatband Reveal Discrete Gap Solitons". In: *Physical Review Letters* 123.11 (Sept. 2019). DOI: 10.1103/physrevlett.123.113901.

[4] Giuseppe Carleo, ... **F. V.**, and Alexander Wietek. "NetKet: A machine learning toolkit for many-body quantum systems". In: *SoftwareX* 10 (July 2019), p. 100311. DOI: 10.1016/j.softx.2019.100311.

[5] **F. V.** et al. *NetKet 3: Machine Learning Toolbox for Many-Body Quantum Systems*. 2021. DOI: 10.48550/ARXIV.2112.10526.

[6] **F. V.**, Riccardo Rossi, and Giuseppe Carleo. "Deep and Autoregressive neural density matrix". In: (2022).

[7] Dian Wu, Riccardo Rossi, **F. V.**, and Giuseppe Carleo. "Mapping Tensor Network States to Recurrent Neural Networks". In: (2022).

[8] Dion Häfner and **F. V.**. "mpi4jax: Zero-copy MPI communication of JAX arrays". In: *Journal of Open Source Software* 6.65 (Sept. 2021), p. 3419. DOI: 10.21105/joss.03419.

[9] Stefano Barison, **F. V.**, and Giuseppe Carleo. "An efficient quantum algorithm for the time evolution of parameterized circuits". In: *Quantum* 5 (July 2021), p. 512. DOI: 10.22331/q-2021-07-28-512.

[10] Stefano Barison, **F. V.**, Ignacio Cirac, and Giuseppe Carleo. *Variational dynamics as a ground-state problem on a quantum computer*. 2022. DOI: 10.48550/ARXIV.2204.03454.

[11] Anna Dawid, ..., and **F. V.** et Al. *Modern applications of machine learning in quantum sciences*. 2022. DOI: 10.48550/ARXIV.2204.04198.