# Martino Sorbaro

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During my PhD, I had the opportunity to build an understanding of both computational neuroscience and machine learning. I am interested in working at the interface between the two fields, with the ultimate goal of understanding the basic principles of learning that are common to brains and machines. I am also committed to open and reproducible science, and passionate about modern teaching techniques and open source software.

## Education

2014–2018 **Erasmus Mundus Doctoral Programme in Neuroinformatics**, *University of Edinburgh & KTH Royal Institute of Technology, Stockholm*.
Thesis title: Statistical modelling of neuronal population activity: from data analysis to network function.
Supervisors: M. Hennig (Edinburgh), A. Kumar (Stockholm).

2011–2013 **Master's degree in Physical Sciences**, *University of Pavia, Italy*.
Final mark: 110/110 with distinction.
Dissertation title: Dynamics of the Kuramoto model on complex networks.
Supervisors: G. Montagna (Pavia), A. Goltsev (Aveiro)

2008–2011 **Bachelor's degree in Physics**, *University of Pavia, Italy*.
Final mark: 110/110 with distinction.
Dissertation title: Some physical applications of artificial neural networks
Supervisor: O. Nicrosini (INFN, Pavia)

### Other schools and courses

2018 **The Carpentries Instructor Training**, *online workshop*.
Training for programming instructors. Evidence-based teaching techniques are covered.

2015 **Advanced scientific programming in Python**, *Summer School*, Munich, Germany.
A course designed to take scientists' Python skills from intermediate to advanced.

2015 **Computational Approaches to Memory and Plasticity**, *Summer School*, NCBS, Bangalore, India.
A two-weeks school in computational neuroscience focused on plasticity.

## Work and Teaching

2019 **Research intern (neuromorphic computing)**, *aiCTX AG*, Zurich, Switzerland.
Translation of modern deep learning algorithms into spiking neural networks, for use in neuromorphic hardware. Current (until February 2020).

2018–2019 **Research assistant**, *Matthias Hennig lab*, University of Edinburgh.

2018 **Deep Learning intern**, *MetaLiquid s.r.l.*, Milan, Italy.
Contribution to the company's Deep Learning software backend, development of software for DL applications (convnets, GANs)

## Teaching experience

2017 **Teaching assistant**, *Computational Approaches to Memory and Plasticity Summer School*, NCBS, Bangalore, India.
Selection of participants, organisation, preparation of talks, assistance with projects. I gave introductory talks about dynamical systems, reinforcement learning, and neural coding.

2016 **Teaching assistant**, *Dynamics and Vector Calculus; Physics 1A; Informatics Research Review*, U. of Edinburgh.
Workshops, tutorials, marking. Teaching award nominations from two students.

2013 **Volunteer**, *Uvikiuta*, Dar Es Salaam, Tanzania.
Private tuition to small groups of students during summer holidays.
Maths and Physics temporary teacher at a high school in a Maasai village.
Contribution to various community development projects and administration.

2012 **Tutor**, *Physics for Biology and Health Sciences students*, U. of Pavia.
Exercise sessions for small groups and classes of up to 40 students.

## Grants and Awards

2016 **Google European Doctoral Fellowship**, *in Computational Neuroscience*.
Given to outstanding students in the field. Involves a significant bursary, contact with a Google mentor, attendance to annual meetings and simplified access to Google internships.

2017 **Best Picture Award**, *at the StratNeuro retreat, Stockholm*.
Prize for the best scientific image among those submitted at a Swedish neuroscience retreat.

## Languages

| | | | |
|---|---|---|---|
| **Italian** | Native | **English** | Fluent (C2) |
| **Portuguese** | Fluent (B2) | **Spanish** | Intermediate (B1) |
| **French** | Basic (A2) | **Swahili** | Very basic (A1) |

## Personal

**Sports and hobbies** International cookery, Fencing, Cycletourism, Climbing, Reading (literature, graphic novels, popular science).

2015–2018 **Committee member**, *Edinburgh University Fencing Club*, (3 academic years).
Website maintenance; publicity and merchandise officer, social media officer.

## Programming

### Skills

| | | | |
|---|---|---|---|
| **Preferred** | Python | **Basics of** | Matlab, C, Scala |
| **Markup** | LaTeX, some HTML | **Tools and techniques** | git, multiprocessing, test-driven development, object-oriented |

### Software Output

**Herding Spikes** Software library for high-density microelectrode array electrophysiology, of which I am an author and maintainer. Freely available at `github.com/mhhennig/HS2`.

**Other** I contributed with a few pull requests to open source libraries (scikit-learn, numpy)

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**Statement of past and present research interests** October 2, 2019

## PhD Research

I have recently completed my PhD in neuroinformatics (jointly at the university of Edinburgh and at KTH, Stockholm) under the supervision of Dr. Matthias Hennig and Dr. Arvind Kumar. My PhD thesis focused on statistical modelling of neural activity, with an approach that spanned from the data processing end, to abstract modelling and network function. This work led to the publications listed in my CV; a copy of the dissertation is available on request.

**Design of a spike sorting algorithm** The initial step of this work focused on improving the data analysis pipeline that leads from the experimental protocol used for dense microelectrode array (MEA) recordings to sorted spike times. The challenge of dense MEAs is that each neuron can be recorded by several electrodes, and each electrode records several neurons, causing a large-scale source separation problem. In collaboration with experimentalists, I contributed to developing a fast and scalable algorithm for spike sorting, which is freely available (`github.com/mhhennig/HS2`) and was published in a Cell Reports article.

**RBMs for the analysis of neural activity** Using the datasets obtained with the method above, I investigated the use of restricted Boltzmann machines (RBMs) in the analysis of retinal recordings and simulated data, finding that they can be used as a tool in the detection of neural ensembles or low-dimensional activity subspaces. I further studied the physical properties of RBMs fitted to neural activity, finding they exhibit signatures of criticality, as observed before in similar models. I studied possible connections between this phenomenon and the "dynamical" criticality often observed in neuronal networks that exhibit emergent behaviour.

**Local learning rules in Hopfield networks** Finally, I applied my findings about the structure of the models' parameter space to the discovery of a learning rule that helps long-term storage of memories in Hopfield networks during sequential learning tasks. Neural networks can exploit knowledge about their own Fisher information in order to preserve "important" parameters from being overwritten. Our work shows that, in Hopfield networks, the Fisher weight can be estimated using only the weight itself: thus, such a learning rule can be implemented locally. However, further research is needed to establish whether this rule is advantageous in practice.

## Other Research Projects

**Neuromorphic computing internship at aiCTX** There are several strategies for training spiking networks, but all are challenging, if the objective is reaching a network that is fully functional in technological applications. I am currently working on the translation of deep learning algorithms into spiking networks, with the ultimate goal of implementing very-low power object detection on neuromorphic hardware.

**Deep Learning Internship at MetaLiquid** I first contributed to the development of the company's proprietary deep learning framework, which gave me the opportunity to understand the software engineering aspects behind deep learning, and allowed me to gain a detailed understanding of the mathematical background. Then, I variously explored the use of convolutional networks, autoencoders, and GANs in practical applications.

**Master's Project** I completed my master's thesis at the university of Aveiro, Portugal, where I worked with prof. Alexander Goltsev in the area of complex networks and complex systems physics. In particular, I looked at the Kuramoto model of synchronisation, applied on a scale-free network, investigating its relaxation rates near the critical point. I obtained analytical results, later confirmed by simulations, which were published in a Physical Review E article. To this day, I am particularly fascinated by nonlinear dynamics and emergent phenomena, even in areas outside of physics, which is one of the reasons that originally led me into computational neuroscience.

## Potential interests for the future

Recently, I have been particularly interested in the intersection between deep learning and neuroscience, at the theoretical and computational level. I have read, with great interest, the recent work that compares the encoding and processing of information in deep convolutional neural networks and in the visual cortex by studying receptive fields, correlation structures, the consequences of ablation, or the role of recurrent connectivity (e.g. Güçlü & van Gerven 2015; Yamins & DiCarlo 2016, Barrett, Morcos, & Macke 2018, Kar et al. 2019).

While this body of recent work shows that there are many promising points of contact between the two fields, there is still a wide gap between them. The most evident difference is that, while some computational principles are similar, artificial and biological networks *learn* in entirely different ways — and backpropagation is a non-local, and therefore non-biological, algorithm. The locality of a learning rule is a necessary condition for its biological plausibility, and makes it easier to implement in neuromorphic hardware, which is exciting for technological applications. Some attempts have been made at finding learning rules that enable the network to learn a task effectively while working locally. One approach is making biologically plausible versions of backpropagation (Scellier and Bengio, 2016; Lillicrap, Cownden, Tweed, & Akerman, 2016), which is necessary for supervised learning. Another is using local rules that enable unsupervised learning, including biologically relevant ones such as STDP (e.g. Savin, Joshi, & Triesch 2010, Diehl and Cook 2015), which can be expanded to include reward-modulated signals (Mozafari et al. 2019).

This "top-down" approach starts with models that, analogously to machine learning, can perform a function, and seeks to find and study learning rules that preserve this function while gradually increasing biological plausibility. I have a strong preference for the literature that adopts this approach and I sincerely believe that this is the one that may prove most fruitful in investigating the foundations of learning in the brain. At the same time, developing a better understanding on how spiking neural networks learn may enable new technological breakthroughs in the growing field of neuromorphic computing, such as efficient on-chip learning.

For my future research work, I would welcome working in any project that involves one or more of these approaches and concepts; but I am, of course, very interested in hearing proposals in other related areas. I have intentionally not included a specific project proposal in this statement.

Finally, I would particularly like to add that I'm committed to open science and open source software development in research. I care about writing good-quality, reusable code, because I am strongly convinced that producing publicly available software, models, or datasets can contribute to scientific development as much as publications. Additionally, I am interested in evidence-based teaching methods and eager to develop my teaching and public engagement skills. To this end, I have recently helped organising machine learning workshops for the general public and have gained the Software Carpentry instructor qualification.