Academic CV

Personal info Name: **Enrico Facca** Date of birth: **30/10/1989** Nationality: **Italian**

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1 Current and previous positions

31/03/2023–Now	Marie Skłodowska-Curie postdoc. researcher at the **University of Bergen** (Norway), supervisor: Jan Martin Nordbotten
01/10/2021–31/03/2023	Postdoc. researcher at **INRIA Lille** (France), supervisor: Andrea Natale
01/10/2019–30/09/2021	Postdoc. researcher at Centro di Ricerca Matematica Ennio De Giorgi **Scuola Normale Superiore in Pisa** (Italy), supervisor: Michele Benzi
01/05/2018–30/09/2019	Postdoc. researcher, **University of Padova** (Italy), supervisor: Mario Putti
01/01/2018–30/04/2018	Scholarship researcher, University of Padova (Italy), supervisor: Mario Putti

2 Training

2.1 Education

01/03/2018	PhD in Computational Mathematics, University of Padova (Italy) Dissertation: Biologically inspired formulation of Optimal Transport Problems Supervisors: Mario Putti, Franco Cardin
14/02/2014	Master degree in Mathematics, University of Padova (Italy)
21/07/2011	Bachelor degree in Mathematics, University of Padova (Italy)

2.2 Mobility

Period	Hosts	Institution/Location
17–24/02/2020	Caterina de Bacco	Max Planck Institute for Intelligent Systems in Tübingen, (Germany)
04–08/03/2019	Kurt Mehlhorn	Max Plank Institute for Informatics, Saarbrüecken (Germany)
01–08/09/2018	Jan Martin Nordbotten	Department of Mathematics, University of Bergen (Norway)
11–14/06/2018	Jean Virieux, Ludovic Metivier	Institut des Sciences de la Terre ISTerre, Grenoble (France)
7-18/12/2016	Filippo Santambrogio	Department of Mathematics, University of Paris Sud (France)
01/10/2015–30/04/2016	Peter Knabner, Aldo Pratelli	Department of Mathematics, Friedrich-Alexander-Universität Erlangen-Nürnberg (Germany)

3 Didactic activities

3.1 Teaching and tutoring

- Responsible for half of the course “Topics in Applied and Computational Mathematics” at the University of Bergen (25 of 50 hours, first semester 2024/25). The course, offered to master and PhD students of Mathematics, covered the study of nonlinear PDEs and optimal transport.
- Responsible for the Matlab laboratory module of the course in numerical calculus for Aerospace Engineering Bachelor of the University of Padova (24 hours, second semester 2018/19).
- Tutor-junior for students of Mathematical Engineering Master of the University of Padova (6 hours, September 2016). This activity offers on demand support for the “Physical-Mathematical models” (prof. Franco Cardin) e Dynamical System MOD. B. (prof. Massimiliano Guzzo).
- Course “Introduction to Physical-Mathematical models” offered to students of the Mathematical Engineering Master of the University of Padova (6 hours, September 2016). This mini-course offered a short introduction of the Lagrangian and Hamiltonian dynamics.

- Tutor-junior for Engineering students of the University of Padova (26 hours, first semester 2013/14). This activity consists of the presentation and solution of calculus exercises. Reference professors: Fabio Ancona and Umberto Marconi.
- Tutor-junior for Engineering students of the University of Padova (25 hours, second semester 2013/14). This activity consists of the presentation and solution of linear algebra exercises. Reference professors: Giovanna Carnovale and Carla Novelli.

3.2 Thesis supervision

- Co-advisor with Prof. Mario Putti of seven master degree theses in Mathematics and Mathematical Engineering at the University of Padova. Andrea Pinto (2015), Enrico Cortese, Claudia Dario (2017), Riccardo Tosi, Luca Berti (2018), Nicola Segala (2019), Nicolo Crescenzio (2021).

We introduce an innovative tool for reconstructing transport networks (e.g., blood vessels, rivers, plant roots) from distorted images. This reconstruction minimizes a problem involving a data misfit term and a physics-based regularizing term from optimal transport theory.

4 Scientific presentations (invited presentation in bold)

– **12/12/2024**. **TMS Colloquium on PDEs**. **Trondheim (Norway)**. "**The optimal transport problem: new tools and new challenges** " (invited talk)

– 29/05/2024. IEEE International Symposium on Biomedical Imaging. Athens (Greece). "Network inpainting via Optimal Transport" (contributed poster)
– **14/05/2024**. **SIAM Conference on Applied Linear Algebra**. **Paris (France)**. "**Preconditioners for the continuous Optimal Transport problem with linear cost**" (invited to mini-symposium)
– **30/08/2023**. **New Directions in Applied Linear Algebra**. **Banff (Canada)**. "**Linear algebra challenges in Optimal Transport problems**" (invited talk)

– 04/07/2023. Intrusion. Bari (Italy). "Network inpainting via Optimal Transport" (contributed talk)

– **20/06/2023**. **SIAM Conference on Mathematical Computational Issues in the Geosciences**. **Bergen (Norway)**. "**Plant roots inpainting**" (invited to mini-symposium)
– **25/10/2022**. **Optimal Transportation and Applications**. **Pisa (Italy)**. "**Iterative methods for interior point algorithms in the L^2 Optimal Transport problem**" (invited talk)

– **28/09/2022**. **Seminar "OptimizEd wORld" at Edinburgh University**. **Edinburgh (UK)**. "**A short journey among Optimal Transport problems and their numerical solution**" (invited talk)
Invited by Prof. Jacek Gondzio – 29/06/2022. 7th IMA Conference on Numerical Linear Algebra and Optimization. Birmingham (UK). "Iterative methods for interior point algorithms in the L^2 Optimal Transport problem" (contributed talk)
– 05/04/2022. 17th Copper Mountain Conference On Iterative Methods. Virtual. "Iterative methods for interior point algorithms in the L^2 Optimal Transport problem" (contributed talk)
– 21/06/2021. 8th European Congress of Mathematics. Virtual. "L^1-Optimal Transport problem on graphs" (contributed talk)

– 02/10/2019. European Numerical Mathematics and Advanced Applications Conference 2019. Egmood aan Zee (Netherland). "Optimal Transport tools on surfaces" (contributed talk)
– **14/04/2019**. **SIAM Conference on Mathematical Computational Issues in the Geosciences**. **Houston (Texas, USA)**. "**Plant root modeling via Optimal Transport**" (invited to mini-symposium)

– **12/04/2019**. **SIAM Conference on Mathematical Computational Issues in the Geosciences**. **Houston (Texas, USA)**. "**Numerical solution of L^1-Optimal Transport problem**" (invited to mini-symposium)

– **15/11/2018**. **Optimal Transportation and Applications**. **Pisa (Italy)**. "**Biologically inspired deduction of Optimal Transport problems**" (invited talk)

– 06/07/2018. SIMAI 2018. Roma (Italy). "Biologically inspired formulation of Optimal Transportation Problems" (contributed talk)

– 04/06/2018. Computational Methods in Water Resources XXIII. Saint Malo (France). "Plant root dynamics via Optimal Transport" (contributed talk)

– 05/04/2018. Terrestrial Systems Research: Monitoring, Prediction and High Performance Computing. Bonn (Germany). "Hydrological networks as optimal transport structures" (contributed talk)
– 11/09/2017. SIAM Conference on Mathematical and Computational Issues in the Geo-sciences. Erlangen, (Germany). "Biologically inspired formulation of Optimal Transportation Problems" (contributed talk)
– 18/12/2014. Current Problems in fluid-dynamics and non equilibrium thermodynamics. Bressanone (Italy). "Biologically inspired formulation of Optimal Transportation Problem" (contributed talk)

5 Conference organization

- Organizer with Angeles Martínez Calomardo, Emma Perracchine, and Federico Piazzon of the workshop "Seminari Padovani di Analisi Numerica 2018" in Padova (04–05/05/2018).
- Organizer with Prof. Jacek Gondzio (University of Edinburgh) of a mini-symposium titled "Iterative Methods of Linear Algebra in Optimization" at the SIAM Conference on Applied Linear Algebra in Paris (13–17/04/2024).

6 Awards

- Marie Skłodowska-Curie Postdoctoral Fellowship 2022–2023 **NIOT** project (score 96.8/100).
- Seal of excellence Marie-Curie IF 2021–2022 for the **NIOT** project (score 87.2/100).

7 Scientific habilitation

Italian scientific habilitation for the scientific sector MATH 01/A5, Numerical Analysis. Valid from 05/11/2024 to 05/11/2035.

8 Software

- NIOT - Reconstruction of corrupted networks.
- DMK - Finite element solver of OT problems based on Dynamical Monge-Kantorovich model introduced in my PhD thesis.
- OT-FV - Finite volumes solver for Benamou-Brenier problem.
- NextRout - Network extraction based on optimal transport tools.

9 General skills

Languages	English (fluent), Italian(native speaker), Spanish(good)
Programming languages	Python, Matlab, Fortran (from Fortran 77 to object-oriented Fortran 2008)
Finite Elements software	Firedrake, Fenics, PETSc4py
General software	Unix-based system, Git, CMake, LaTeX

10 Research records

10.1 Research activities overview

My main research activities focus on numerical solution of Optimal Transport (OT) problems, in particular those based on PDEs. My contributions in this field are the result of an original formulation I introduced

in my master thesis, the Dynamical Monge-Kantorovich (DMK) approach. This formulation later became my PhD topic, supervised by Prof. Mario Putti and Prof. Franco Cardin from University of Padova. It led to the development of accurate and efficient numerical solvers for the OT problem with cost equal to the Euclidean distance (also called L^1-OT problem) described in [1, 2, 4, 5, 18, 11]. An extension of the model, presented in [3], was related to the p-Laplacian equations and the branched transport problem, a sub-area of OT studying ramified structures.

In [8], I started working on linear algebra problems arising from the solution of the OT problems, with the aim of improving the efficiency of related numerical methods. In 2019, I moved to Scuola Normale Superiore (Pisa) to collaborate with Prof. Michele Benzi on this topic. In [7*], we showed that the OT problem on graphs can be solved with the CPU time scaling slightly more than linearly with respect to the size of the problem. Throughout this two-year postdoctoral position, I gained extensive knowledge on preconditioning methods for PDEs and optimization problems.

In 2021, I joined the RASPODI team at INRIA Lille. I worked with Andrea Natale on the numerical solution of a dynamical formulation of the OT problem with quadratic cost via interior point methods. Combining our expertise, we designed an iterative method capable of efficiently solving large-scale problems, described in [6*].

In 2023, I was awarded the Marie Sklodowska-Curie postdoctoral fellowship for the project Network Inpainting via Optimal Transport (**NIOT**) with Prof. Jan Martin Nordbotten at the University of Bergen. The goal of the project is to reconstruct blood vessel networks in corrupted magnetic resonance images using branched transport tools introduced in [3]. The main mathematical ideas behind the project are described in [17*], currently under review.

The network of my collaborators includes Prof. Kurt Mehlhorn (Emeritus scientist at the Max Planck Institute for Computer Science in Saarbrücken) and Dr. Caterina de Bacco (TU Delft) on applications and extensions of the OT theory. These collaborations lead to the publication of manuscripts [9, 10*, 12*, 15, 16*].

My long-term ambition is to make the mathematical and numerical tools of OT widely used in applied sciences. I plan to focus on inverse problems that come, for example, from geoscience and biomedical applications, like the ones in the **NIOT** project.

10.2 Publications

Number of publications:	Peer-reviewed journal articles: 16, submitted: 2
Google Scholar:	documents: 18, h-index: 10, citations: 277
Scopus:	documents: 15, h-index: 8, citations: 121
WoS:	documents: 14, h-index: 8, citations: 113

In this section, my publications are organized according to broad research topics. **The titles of the 12 publications submitted for evaluation are in bold.** Each manuscript includes a brief overview that details its content and key achievements. Manuscripts that I authored without the collaboration of my PhD supervisors are highlighted with an asterisk on their number.

10.2.1 Manuscripts on OT problems

These manuscripts contain the theoretical and numerical analysis of the DMK model.

Journal articles

[1] L. Berti, E. Facca, and M. Putti. "Numerical solution of the L^1-optimal transport problem on surfaces". In: Advances in Computational Science and Engineering 1.4 (2023).
We studied the convergence of a finite element approach for solving the OT problem on surfaces. The results in this paper were used in [12].

[2] E. Facca, F. Piazzon, and M. Putti. "L^1 **Transport Energy**". In: Applied Mathematics and Optimization 86.2 (2022).
We studied a gradient flow approach for the solution of L^1-OT problem inspired by the DMK model.

[3] E. Facca, F. Cardin, and M. Putti. "**Branching structures emerging from a continuous optimal transport model**". In: Journal of Computational Physics 447 (2021).
We proposed an extension of the DMK model used to solve p-Laplacian equations and branched transport problems. The ability of this model to generate branching structures plays a fundamental role in the NIOT approach introduced in my Marie Skłodowska-Curie project.

[4] E. Facca, S. Daneri, F. Cardin, and M. Putti. "**Numerical solution of Monge–Kantorovich Equations via a Dynamic Formulation**". In: Journal of Scientific Computing 82.3 (2020).
We proposed a finite element scheme for the accurate solution of the L^1-OT problem based on the DMK approach. We showed how to cope with the emergence of checkerboard instabilities. Similar strategies were adopted in [7].*

[5] E. Facca, F. Cardin, and M. Putti. "**Towards a Stationary Monge–Kantorovich Dynamics: The Physarum Polycephalum Experience**". In: SIAM Journal on Applied Mathematics 78.2 (2018).
We introduced the DMK model, analyzing the existence and uniqueness of the associated equations. We showed the connection with the OT problem with Euclidean cost.

10.2.2 Manuscripts on linear algebra problems

These manuscripts contain my work on the development of efficient linear algebra strategies for the numerical solution of different OT problems.

Journal articles

[6*] E. Facca, G. Todeschi, A. Natale, and M. Benzi. "**Efficient Preconditioners for Solving Dynamical Optimal Transport via Interior Point Methods**". In: SIAM Journal on Scientific Computing 46.3 (2024).
We studied the numerical solution via Newton-based methods of the dynamical formulation of the OT problem with cost equal to the quadratic Euclidean distance. We proposed a preconditioning approach able to solve large-scale 2d and 3d problems with a CPU time scaling slightly more the linearly with respect to the number of degrees of freedom.

[7*] E. Facca and M. Benzi. "**Fast Iterative Solution of the Optimal Transport Problem on Graphs**". In: SIAM Journal on Scientific Computing 43.3 (2021).
We solved an OT problem on graphs using a Newton-based approach, analyzing different preconditioning strategies to solve the associated linear systems. We showed that this problem can be solved with CPU time scaling slightly more than linearly with respect to the problem size, improving previous results that suggested a quadratic time complexity.

[8] L. Bergamaschi, E. Facca, A. Martínez Calomardo, and M. Putti. "**Spectral preconditioners for the efficient numerical solution of a continuous branched transport model**". In: Journal of Computational and Applied Mathematics 354 (2018).
We proposed an ad-hoc preconditioning strategy to solve the sequence of linear systems arising from the DMK model when applied to branched transport problems.

10.2.3 Manuscripts on applications of the optimal transport problem

These manuscripts contain a series of applications related to the OT problems and the DMK model.

Journal articles

[9] A. Lonardi, E. Facca, M. Putti, and C. De Bacco. "**Infrastructure adaptation and emergence of loops in network routing with time-dependent loads**". In: Physical Review E 107 (2023).
We studied how fluctuating loads in transport systems led to the formation of loops.

[10*] V. Bonifaci, E. Facca, F. Folz, A. Karrenbauer, P. Kolev, K. Mehlhorn, G. Morigi, G. Shahkarami, and Q. Vermande. "**Physarum-inspired multi-commodity flow dynamics**". In: Theoretical Computer Science 920 (2022).
We proposed a numerical scheme for solving an OT problem where multiple resources are moved within a network.

[11] E. Facca, L. Berti, F. Fassò, and M. Putti. "**Computing the cut locus of a Riemannian manifold via optimal transport**". In: ESAIM: Mathematical Modelling and Numerical Analysis 56.6 (2022).
We connected the L^1-OT problem with the geometrical concept of the cut locus of a Riemannian manifold, providing a novel and efficient method for its approximation based on the DMK model.

[12*] D. Leite, D. Baptista, A. A. Ibrahim, E. Facca, and C. De Bacco. "Community detection in networks by dynamical optimal transport formulation". In: Scientific Reports 12.1 (2022).
We combined OT tools with the Oliver-Ricci flow to detect communities in graphs.

[13] A. Lonardi, E. Facca, M. Putti, and C. De Bacco. "Designing optimal networks for multicommodity transport problem". In: Physical Review Research 3 (2021).
We presented an effective method for solving transport problems where various commodities are moved across networks, while concentration during the transportation is either penalized or favored.

[14] B. Mary, L. Peruzzo, V. Iván, E. Facca, G. Manoli, M. Putti, M. Camporese, Y. Wu, and G. Cassiani. "Combining Models of Root-Zone Hydrology and Geoelectrical Measurements: Recent Advances and Future Prospects". In: Frontiers in Water 3 (2021).
We explored the connection between the branched transport problems and plant roots modeling.

[15] D. Baptista, D. Leite, E. Facca, M. Putti, and C. D. Bacco. "**Network extraction by routing optimization**". In: Scientific Reports 10.1 (2020).
We proposed an application of the branched DMK model for extracting optimal sub-networks from existing graphs. The NextRout solver was released.

[16*] E. Facca, A. Karrenbauer, P. Kolev, and K. Mehlhorn. "**Convergence of the non-uniform directed Physarum model**". In: Theoretical Computer Science 816 (2020).
We analyzed a physarum-inspired solver for linear programming problems.

10.2.4 Preprints

Preprints

[17*] E. Facca, J. M. Nordbotten, and E. A. Hanson. "Network Inpainting via optimal transport". arXiv preprint. 2024.

[18] F. Piazzon, E. Facca, and M. Putti. "Computing the L^1 optimal transport density: a FEM approach". (2023) arXiv preprint
We studied the convergence of a finite element scheme for the discretization of the gradient flow approach described in [2].

I declare that everything declared in this document is true, according to articles 46 e 47 of D.P.R. 445/2000.
Bergen, February 22, 2025