LEONARDO FELIPE TOSO

M.S., M.Eng., and B.Eng. in Electrical Engineering

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PROFILE

I am a Presidential fellow and second-year Ph.D. student in the Department of Electrical Engineering at Columbia University, where I am advised by James Anderson. Prior to joining Columbia, I was a undergrad research assistant in the Department of Engineering Science at the University of Oxford, under the supervision of Stephen Duncan and Ross Drummond. I was awarded my M.S. in Control, Signal, and Image Processing from the University of Paris-Saclay and the M.Eng. in Control Engineering from CentraleSupélec in 2022, where I worked with Giorgio Valmorbida. In addition, I received my B.Eng. in Electrical Engineering from the University of Campinas (Unicamp) in 2022, working with Matheus Souza.

RESEARCH INTERESTS

My research interests lie in the intersection between **control theory**, **machine learning**, and **optimization**, which include:

• Multi-task Learning • Federated Learning • Large Scale Inference • Representation Learning • Linear and Non-linear Control • Adaptive Control • Hybrid Systems • Fluid Flow Systems.

EDUCATION

2022 - Present **Columbia University** — **New York, USA**
Ph.D. Candidate in Electrical Engineering and Presidential Fellow. **GPA:** 4.13/4

2020 - 2022 **University of Paris-Saclay** — **Paris, France**
M.S. in Electrical Engineering. **GPA:** 3.9/4

2019 - 2022 **CentraleSupélec** — **Paris, France**
M.Eng. in Electrical Engineering. **GPA:** 4.31/4

2016 - 2022 **University of Campinas (Unicamp)** — **Sao Paulo, Brazil**
B.Eng. in Electrical Engineering (1st in class award). **Cumulative Grade Average:** 9.4/10.

LANGUAGES

English - Full Professional Proficiency, **French** - Full Professional Proficiency, **Portuguese** - Native.

RESEARCH EXPERIENCES

2023 **Meta-Learning Linear Quadratic Regulators** — **Columbia University**
In collaboration with Donglin Zhan, Han Wang and James Anderson, we proposed a policy gradient MAML-based approach for solving the multi-task and model-free LQR problem. We showed that the MAML-LQR approach produces a stabilizing controller close to each task-specific optimal controller up to a task-heterogeneity. In contrast to existing MAML-LQR results, our theoretical guarantees demonstrate that the learned controller can efficiently adapt to unseen LQR tasks.

2023 **Stochastic Variance-Reduced Policy Gradient for the Model-free LQR** — **Columbia University**
In collaboration with Han Wang and James Anderson, we proposed a stochastic variance reduced approach for solving the model-free linear quadratic regulator problem. Whilst policy gradient methods have proven to converge linearly to the optimal solution of the model-free LQR problem, the substantial requirement for two-point cost queries in gradient estimations may be intractable, particularly in applications where obtaining cost function evaluations at two distinct control input configurations is exceptionally costly. To this end, we proposed an oracle-efficient approach that combines both one-point and two-point estimations in a dual-loop variance-reduced algorithm to reduce the oracle complexity.

2023 **Learning Linear Representation from Multi-task, Non-IID, and Non-isotropic Data** — **Columbia University**
In collaboration with Thomas T.C.K. Zhang, James Anderson, and Nikolai Matni, we studied the problem of learning a linear representation from a multi-task, non-iid and non-isotropic dataset. The non-iid and non-isotropy introduces bias and prevents us from achieving the desired contraction when learning the representation. We then proposed a fix through `De-bias & Feature-Whiten` (DFW) for the alternating minimization-descent (AMD) scheme proposed in Collins et al., (2021). We also established linear convergence to the optimal representation with noise level scaling down with the total source data size.

2023 **Learning Personalized Linear Models via Clustering and Multi-agent Identification** **Columbia University**
In collaboration with Han Wang and James Anderson, we proposed a clustered system identification approach for learning linear system models from observing multiple trajectories from different system dynamics. This framework encompasses a collaborative scenario where several systems seeking to estimate their dynamics are partitioned into clusters according to their system similarity. We show that our approach correctly estimates the cluster identities and achieves an approximate sample complexity that scales inversely with the number of systems in the cluster without suffering from a heterogeneity bias.

2022 - 2023 **Federated Learning for Model-free Linear Quadratic Regulator** **Columbia University**
In collaboration with Han Wang and James Anderson, we proposed a federated learning approach for solving the multi-agent and model-free linear quadratic regulator problem with heterogeneous dynamics. The aim of this project was to investigate the benefit of collaboration when learning a common policy for all the agents by leveraging trajectory data across them. We showed that our approach produces a common policy that, at each iteration, is stabilizing for all agents, and showed that the learned policy is approximate close to each agent's optimal up to heterogeneity bias.

2022 **FedSysID: A Federated Approach to Sample-Efficient System Identification** **Columbia University**
In collaboration with Han Wang and James Anderson, we proposed a federated learning approach for learning a linear system model from the observations of M clients. This work addresses the question of how multiple clients collaboratively learn dynamical models in the presence of heterogeneity. We showed that federated sample complexity result achieves a reduction proportional to the number of clients compared to the single-agent sysID counterpart.

2021-2022 **Synthesis of Control Laws for Switching Systems with Dwell-time Constraints** **University of Campinas**
This project was carried out under the supervision of Professor Matheus Souza. It consisted of the stability analysis and design of control laws for switching systems while satisfying dwell-time constraints.

Apr-Oct/2021 **Predicting the Transition to Turbulence using Sum-of-Squares Programming** **University of Oxford**
This project was carried out under the supervision of Professors Stephen Duncan and Ross Drummond. It consisted of the global and regional stability analysis of transitional fluid flow systems by solving differential matrix inequalities via sum-of-squares programming.

Jan-Apr/2021 **Model predictive control for Autonomous Vehicles** **CentraleSupélec**
This project was carried out under the supervision of Professor Emmanuel Godoy from CentraleSupélec and Doctor Pepe Sene from Renaut Group. It consisted of studying model predictive control for an autonomous shuttle bus to be implemented for the Olympics Games in Paris in 2024.

2020-2021 **Stability Certificates for Linear Hybrid Systems via Handelman decomposition** **University of Paris-Saclay**
This project was carried out under the supervision of Professor Giorgio Valmorbida. It consisted of the stability analysis of hybrid systems with periodic jumps. This project aimed to formulate the stability conditions via differential matrix inequalities and solve them by exploiting different non-negativity analysis approaches, such as Sum-of-Squares (SoS), Pólya and Handelman decomposition.

2019-2021 **Stability Analysis and Control laws for Linear Hybrid Systems** **CentraleSupélec**
This project was carried out under the supervision of Professor Giorgio Valmorbida. It consisted of the stability analysis and design of control laws linear hybrid systems. This project exploited Lyapunov-based stability conditions and SoS programming to formulate and solve differential matrix inequalities.

2019-2020 **Pre-and Post-processing Algorithms for the SOSPy** **CentraleSupélec**
This project was carried out under the supervision of Professor Giorgio Valmorbida. It consisted of developing and implementing pre-and post-processing algorithms for the SOSPy. Multiple numerical algorithms, such as Newton's polytype, diagonal inconsistency and block diagonalization was implemented to reduce the dimensions of the corresponding semi-definite programming to reduce the processing and solving time of the SOSPy.

2019-2020 **Python Library SOSPy** **CentraleSupélec**
In collaboration with Professor Giorgio Valmorbida, we developed a Python-based library for solving sum-of-squares programming. The aim of this toolbox was to reach a broader user base, to allow Python users to formulate and solve sum-of-squares programs.

2018-2019 **Stability Analysis and Design of Control Laws for Switching Systems** **University of Campinas**
This project was carried out under the supervision of Professor Matheus Souza. It contributed to the study of stability analysis and control laws based upon Lyapunov-based stability conditions for switching systems.

2017-2018 **Stability Analysis and Fault Detection for Power Systems** **University of Campinas**
This project was carried out under the supervision of Professor Maria Cristina. It contributed to the study of stability analysis and protection of power transformers.

PROFESSIONAL EXPERIENCE

Apr-Oct/2021 **French Research Internship Program** **University of Oxford**

This six-month research internship was carried out under the supervision of Professor Stephen Duncan and Doctor Ross Drummond. It was part of a French research internship program between the University of Oxford, CentraleSupélec and EDF Energy UK. EDF Energy UK founded internship through the sponsor license number UED4UGNF1.

PAPERS

- **LF. Toso**, D. Zhang, J. Anderson, H. Wang, "Meta-Learning Linear Quadratic Regulators: A Policy Gradient MAML Approach for the Model-free LQR". Under review, 2024.
- TTCK. Zhang, **LF. Toso**, J. Anderson, N. Matni, "Sample-Efficient Linear Representation Learning from Non-IID Non-Isotropic Data". International Conference on Learning Representations 2024 **(spotlight presentation - top 5%)**.
- **LF. Toso**, H. Wang, J. Anderson, "Oracle Complexity Reduction for Model-free LQR: A Stochastic Variance-Reduced Policy Gradient Approach". American Control Conference 2024.
- H. Wang, **LF. Toso**, A. Mitra, J. Anderson, "Model-free Learning with Heterogeneous Dynamical Systems: A Federated LQR Approach". Under review, 2023.
- **LF. Toso**, H. Wang, J. Anderson, "Learning Personalized Models with Clustered System Identification". Conference on Decision and Control 2023.
- H. Wang, **LF. Toso**, J. Anderson, "FedSysID: A Federated Approach to Sample-Efficient System Identification". Learning for Dynamics & Control Conference 2023.
- **LF. Toso**, R. Drummond, S. Duncan, "Regional stability analysis of transitional fluid flows". IEEE Control Systems Letters, 2022.
- **LF. Toso**, G. Valmorbida, "Lyapunov Function computation for Periodic Linear Hybrid Systems via Handelman, Polya and SoS approaches: A comparative study". IFAC Control Applications of Optimization, 2022.

PAPERS IN PREPARATION

- **LF. Toso***, H. Wang*, J. Anderson "Asynchronous Distributed Model-free LQR Design with Heterogeneous Systems Dynamics", 2024.
- BD. Lee, **LF. Toso**, TTCK. Zhang, J. Anderson, N. Matni "Regret Analysis of Multi-task Representation Learning for Linear Quadratic Control", 2024.
- P. Munar, **LF. Toso**, J. Anderson, "Optimizing General Anesthesia: A Unified Model paired with Model Predictive Control and Extended Kalman Filtering", 2024.

SOFTWARE

- **LF. Toso**, Z. Mo, J. Anderson, "SOSPy: A Python library for solving sum-of-squares programming".

GRANTS AND AWARDS

2022 **Presidential Fellowship** **Columbia University**

Selected amongst outstanding applicants to receive the Presidential Fellowship for funding the Ph.D. studies at Columbia University.

2022 **First in Class Award** **University of Campinas**

Selected to receive an award from the Regional Council of Engineering (CREA-SP) for finishing first in class the B.S. in Electrical Engineering at the University of Campinas in 2022.

2021 **FAPESP Research Scholarship Program** **University of Campinas**

Selected to receive a scholarship from the Foundation for Research Support of the State of São Paulo (FAPESP) for funding the project on "Control Design for Switching Systems with Dwell-time Constraints".

2019 **BRAFITEC Scholarship Program of Excellence** **CentraleSupélec**

Selected to receive a scholarship based on academic excellence to study in Paris, France.

2018 **CNPq Research Scholarship Program** **University of Campinas**
Selected to receive a scholarship from the National Council for Scientific and Technological Development (CNPq) for funding the project on "Analysis and Synthesis of Switching Systems".

2017 **CNPq Research Scholarship Program** **University of Campinas**
Selected to receive a scholarship from the National Council for Scientific and Technological Development (CNPq) for funding the project on "Stability Analysis and Fault Detection in Power Systems".

PRESENTATIONS AND WORKSHOPS

2023 **62nd Conference on Decision and Control (CDC)** **Singapore**
Oral presentation on the main results of the paper "Learning Personalized Models with Clustered System Identification".

2023 **Learning for Dynamics & Control Conference (L4DC)** **University of Pennsylvania**
Poster presentation on the main results of the paper "FedSysID: A Federated Approach to Sample-Efficient System Identification".

2022 **18th IFAC Workshop on Control Applications of Optimization** **CentraleSupélec**
Oral presentation on the main results of the paper "Lyapunov Function computation for Periodic Linear Hybrid Systems via Handelman, Polya and SoS approaches: A comparative study".

2021 **L2S Poster Presentation** **CentraleSupélec**
Poster presentation on the main results of the project on "Pre-and Post-Processing Algorithms for Sum-of-Square Programming".

2019 **XXVII Scientific Research Conference (CNPq)** **University of Campinas**
Poster presentation on the main results of the project on "Stability Analysis and Controller Design for Switching Systems".

2018 **XXVI Scientific Research Conference (CNPq)** **University of Campinas**
Poster presentation on the main results of the project on "Stability Analysis and Fault Detection in Power Systems".

TEACHING EXPERIENCE

Over the past few years I had the pleasure of serving as a head Teaching Assistant (TA) for:

- **Convex Optimization**, Fall 2023. Columbia University.
- **Modern Control Theory**, Spring 2023. Columbia University.
- **Convex Optimization**, Fall 2022. Columbia University.
- **Control Theory**, Spring 2022. University of Campinas.
- **Circuit Analysis** I, Fall 2018. University of Campinas.
- **Calculus I**, Fall 2017. University of Campinas.

MENTORING

Over the Summer and Fall of 2023, I had the pleasure of mentoring outstanding M.S. EE students at Columbia University:

- Patrick Munar on "Optimizing General Anesthesia: A Unified Model paired with Model Predictive Control and Extended Kalman Filtering" (paper in preparation).
- Zhe Mo on "SOSPy: A Python library for solving sum-of-squares programming".

ACADEMIC SERVICE

I have been serving as a peer reviewer for:

- IEEE Transactions on Automatic Control (TAC).
- IEEE Control Systems Letters (L-CSS).
- IEEE Transactions on Vehicular Technology (TVT)
- Learning for Dynamics & Control Conference (L4DC).
- IEEE Conference on Decision and Control (CDC).
- American Control Conference (ACC).

- International Federation of Automatic Control (IFAC).

OUTREACH/VOLUNTEER PROJECT

SANQUIM NGO **Volunteer Tutor of Physics and Mathematics** **Sao Paulo, Brazil**
Volunteer project once a week in a non-governmental organisation in Mogi-Mirim, São Paulo, Brazil, carrying out activities as a physics and mathematics tutor and teaching children in underprivileged conditions.

TECHNICAL SKILLS

- **Graduate Coursework:** Probabilistic Models for Machine Learning (David Blei, Columbia University), High-Dimensional Probability with Applications (Kaizheng Wang, Columbia University), Sparse and Low-Dimensional Models for High-Dimensional Data (John Wright, Columbia University), Estimation Theory (Michel Kieffer, University of Paris-Saclay), Stability of Nonlinear Systems (Antoine Chaillet and Giorgio Valmorbida, University of Paris-Saclay), Hybrid System (Antoine Girard, University of Paris-Saclay), Multi-Agent Systems (Elena Panteley, University of Paris-Saclay).
- **Programming Languages:** Python, MATLAB, C, C++.
- **Tools:** Gymnasium, PyTorch, Yalmip, Gurobi, Mosek, CVX, CVXPY, SOSTOOLS, SOSPy, LaTeX.

REFERENCES

- **James Anderson:** Department of Electrical Engineering, Columbia University, `james.anderson@columbia.edu`
- **Stephen Duncan:** Department of Engineering Science, University of Oxford, `stephen.duncan@eng.ox.ac.uk`
- **Giorgio Valmorbida:** Signals and Systems Lab, CentraleSupélec, `giorgio.valmorbida@centralesupelec.fr`
- **Matheus Souza:** Department of Electrical Engineering, University of Campinas, `msouza@fee.unicamp.br`
- **Ross Drummond:** Department of Automatic Control, University of Sheffield, `ross.drummond@sheffield.ac.uk`