Licio Romao

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Research Interests

I am currently interested in data-driven methods to design of feedback controllers. The focus of my research is on abstractions of discrete-time stochastic systems and on theoretical foundations of optimisation algorithms, especially chance-constrained optimisation problems. Two of my recent papers focus on distributionally robust dynamic programming and reinforcement learning.

Education

- **University of Oxford, Engineering Science Department** — Oxford, United Kingdom
  DPhil in Engineering Science — *October 2017 - August 2021*
  Funded by CAPES, Ministry of Education, Brazil
  Competitive scholarship. More than 2000 applicants to 120 scholarships for all areas
  Supervisors: Prof. Antonis Papachristodoulou and Prof. Kostas Margellos
- **University of Campinas, School of Electrical and Computer Engineering** — Sao Paulo, Brazil
  MSc in Control Engineering, GPA:4/4 — *September 2014 - February 2017*
  Title: Filter design for linear systems with H-2, H-infinity and H-infinity in frequency interval criteria by means of matrix inequalities
  Supervisor: Prof. Pedro Luis Dias Peres
- **UFCG (Federal University of Campina Grande)** — Campina Grande, Brazil
  BS in Electrical Engineering, GPA: 9.08/10 (top 2% of cohort) — *April 2008 - July 2014*

Professional Experience

- **University of Oxford, Computer Science Department** — Oxford, United Kingdom
  Postdoctoral fellow — *April 2021 - present*
  - Under the supervision of Prof. Alessandro Abate
  - Abstraction of stochastic systems. Formal verification. Reinforcement learning. Discrete-time stochastic systems.
- **University of Bologna** — Bologna, Italy
  Visiting scholar — *July 2019*
  - Working with Prof. Giuseppe Notarstefano
  - Multi-agent optimisation.
- **University of California San Diego, UCSD** — San Diego, United States
  Visiting scholar — *November 2015 - April 2016*
  - Working with Prof. Mauricio de Oliveira
  - Generalized Kalman-Yakubovich-Popov (KYP) lemma.

Awards

- **IET Control and Automation Doctoral Dissertation Prize 2021.** A prestigious award from *the Institution of Engineering and Technology* (IET) that recognises significant achievements in the area of control engineering.
- **2022 AAAI distinguished paper award.** For the results in the paper T. Badings, L. Romao, A. Abate, D. Parker, H. Poonawala, N. Jensen. Robust Control for Dynamical Systems with Non-Gaussian Noise via Formal Abstractions. JAIR.

Funding

- **CAPES graduate scholarship** *(August 2017)* Prestigious scholarship awarded by the Brazilian Ministry of Education to pursue a PhD in Engineering Science at the University of Oxford.
- **FAPESP scholarship** *(April 2014)* Competitive scholarship awarded by the Sao Paulo Research Foundation (FAPESP), Brazil, to pursue a master's degree at the University of Campinas, SP, Brazil.
- **FAPESP research internships abroad** *(September 2015)* To spend six months as a visiting scholar at the University of California, San Diego.

Teaching Experience

- **Modern Control Theory**
  Graduate course, Department of Engineering Science, University of Oxford
  - Organisers: Prof. Kostas Margellos & Prof. Alessandro Abate
  - Lecturer. Delivering lectures on optimisation, duality theory, LMIs, S-procedure, dynamic programming, and controller design using SDPs.
  - Students' feedback: "Licio in particular was an amazing teaching assistant, he went out of his way to explain concepts thoroughly and did a great job lecturing when the other lecturer fell ill"; "Licio was a great TA and explained in lots of detail."
- **Probabilistic Model Checking**
  Graduate/undergraduate course, Department of Computer Science, University of Oxford
  - Organiser: Prof. Alessandro Abate
  - Holding tutorial sessions with the students.
  - Students' feedback: "Always prepared; Punctual; Knowledgeable about everything; Explains questions on assignments very well; Patient on answering all questions"; "It is clear that he had a very good understanding of the material and also a very strong intuition regarding potential issues we may have. He provided alternative solutions and interpretations for most problems and really enhanced our understanding of the material."
- **Modern Control Theory**
  Graduate course, Department of Engineering Science, University of Oxford
  - Organisers: Prof. Kostas Margellos, Prof. Paul Goulart & Prof. Alessandro Abate
  - Producing a set exercises and assisting the students with topics in modern control theory.
- **B15: Control Systems**
  3^{rd}*-year undergraduate course, Department of Engineering Science, University of Oxford*
  - Teaching assistant. Solving exercise sets with the students, and helping them solidifying concepts learned during the lectures.
  - Students' feedback: "Licio's been a brilliant tutor this year. I found B15 quite challenging overall but Licio was incredibly supportive and provided good explanations, and extra little resources during the tutorial which were also very helpful."; "Very good tutor. Even provided his own notes on the subject so as to give us another explanation/description of the topics which was very helpful. Good explainer. He would sometimes ask us to run through a problem on the board which would keep us on our toes, but it's good to try these out as a student, as you can show him step-by-step what you're doing which is good for learning."
- **C20: Linear Matrix Inequalities & Robust Control**
  4^{th}*-year undergraduate course, Department of Engineering Science, University of Oxford*
  - Course organiser: Prof. Kostas Margellos
  - Producing and solving a set of exercises on duality theory.
- **LEGO Football Coursework Module**
  2^{nd}*-year undergraduate course, Department of Engineering Science*
  - Course organiser: Prof. Kostas Margellos
  - **Lead tutor** for two consecutive years in a week-long lab. Main topics: root locus and state-feedback design to stabilise a model of an inverted pendulum.
- **EA614: Signal Analysis**
  3^{rd}*-year undergraduate course, University of Campinas*
  - Course organiser: Prof. Pedro Luis Dias Peres
  - **Lead tutor.** Main topics: convolution, continuous and discrete-time Fourier transform. Laplace transform.

Supervision

Ongoing

- **Catalin Dumitru** (with Prof. Alessandro Abate) MSc. in Computer Science, University of Oxford. Exploring connections between a recent paper of mine about RL robustness and a two-player game setting.
- **Adrian Capraru** (with Prof. Alessandro Abate) MSc. in Computer Science, University of Oxford. Developing a computational toolbox to perform distributionally robust PCTL model checking.

Completed

- **Luke Rickard** (with Prof. Alessandro Abate) Ph.D. student at the AIMS program, University of Oxford. Rotational project. Extending an abstraction technique that leverages the scenario approach theory to the design of reach-avoid controllers for Markov jump linear systems.
- **John Ryan** (with Prof. Alessandro Abate) MSc. in Computer Science, University of Oxford. Applying reinforcement learning techniques for controlling the OPS-SAT satellite. In collaboration with the European Space Agency (ESA).
- **Thomas Koeck** (with Prof. Alessandro Abate) MSc. in Computer Science, University of Oxford. Combining reinforcement learning algorithms and robust control to space applications. In collaboration with Airbus.
- **Ming Ow** (with Prof. Kostas Margellos) MSc. in Engineering Science, University of Oxford. Studying chance-constrained optimisation. Applying the results developed in one of the chapters of my PhD thesis to the optimal power flow problem.

Publications

Pre-prints

- A. Banse, **L. Romao**, A. Abate, R. Jungers. Data-driven memory-dependent abstractions of dynamical systems. Under review at the 5th Annual Learning for Dynamics & Control Conference (L4DC).
- D. Jarne Ornia, **L. Romao**, M. Mazo Jr, A. Abate. Observational Robustness and Invariances in Reinforcement Learning via Lexicographic Objectives. Under review at the International Conference on Machine Learning (ICML).
- L. Rickard, T. Badings, **L. Romao**, N. Jansen, A. Abate. Formal Controller Synthesis for Markov Jump Linear Systems with Uncertain Dynamics. Under review at the 5th Annual Learning for Dynamics & Control Conference (L4DC).

Journal papers

- T. Badings, **L. Romao**, A. Abate, D. Parker, H. Poonawala, N. Jensen. Robust Control for Dynamical Systems with Non-Gaussian Noise via Formal Abstractions. *Award-winning 2022 AAAI paper*. Journal of Artificial Intelligence Research (JAIR).
- **L. Romao**, K. Margellos, A. Papachristodoulou. Probabilistic feasibility guarantees for convex scenario programs with an arbitrary number of discarded constraints. Automatica, 148, 1–9. 2023.
- **L. Romao**, K. Margellos, A. Papachristodoulou. On the exact feasibility of convex scenario programs with discarded constraints. *IEEE Transaction on Automatic Control*. Early Access.
- **L. Romao**, K. Margellos, G. Notarstefano, A. Papachristodoulou. Subgradient averaging for multi-agent optimisation with different constraint sets. Automatica. Vol. 131. 109738. 2021.
- **L. Romao**, K. Margellos, A. Papachristodoulou. Distributed Actuator Selection: Achieving Optimality via a Primal-Dual Algorithm. IEEE Control Systems Letters. Vol. 2. No. 4. 779–784. 2019.

Conference papers

- T. Badings, **L. Romao**, N. Jensen, A. Abate. Probabilities Are Not Enough: Formal Synthesis for Stochastic Dynamical Models with Epistemic Uncertainty. To appear in the proceedings of the 37th AAAI Conference on Artificial Intelligence. 2023.
- **L. Romao**, K. Margellos, A. Papachristodoulou. Tight sampling and discarding bounds for scenario programs with an arbitrary number of removed samples. 3rd Annual Learning for Dynamics & Control Conference (L4DC). 2021.
- **L. Romao**, K. Margellos, A. Papachristodoulou. Tight generalization guarantees for the sampling and discarding approach to scenario optimization. 59-th Conference on Decision and Control. 2020.
- **L. Romao**, K. Margellos, G. Notarstefano, A. Papachristodoulou. Convergence rate analysis of a subgradient averaging algorithm for distributed optimisation with different constraint sets. 58-th Conference on Decision and Control. 2019.
- **L. B. R. R. Romao**, M. C. de Oliveira, P. L. D. Peres, R. C. L. F. Oliveira. H-infinity filter design with low- and middle-frequency specifications for continuous-time linear systems: LMI conditions derived from two different extensions of the KYP lemma. 2018 American Control Conference. 2018.
- **L. B. R. R. Romao**, Luciano Frezzatto, M. C. de Oliveira, R. C. L. F. Oliveira, P. L. D. Peres. Non-minimal order low-frequency H-inf filtering for uncertain discrete-time systems. IFAC International Federation on Automatic Control. 2017.
- **L. B. R. R. Romao**, M. C. de Oliveira, P. L. D. Peres, R. C. L. F. Oliveira. State-Feedback and Filtering Problems using the Generalized KYP Lemma, IEEE Multi-Conference on Systems and Control. 2016.
- **L. B. R. R. Romao**, R. C. L. F. Oliveira, P. L. D. Peres. Projeto de Filtros Robustos H2 usando LMIs com Escalares, XII SBAI Simpósio Brasileiro de Automação Inteligente. 2015.
- **L. B. R. R. Romao**, P. L. D. Peres, R. C. L. F. Oliveira. H-infinity Robust Filter Design for Continuous-Time Linear Systems Using LMIs with a Scalar Parameter, XXI Congresso Brasileiro de Automática, 2016.

Research experience

My research interests lie in the development of safer and interpretable data-driven controller design methods by leveraging tools from stochastic calculus and statistical learning theory. My research has focused on theoretical foundations of a randomised approximation for chance-constrained problems, on correct-by-design controller synthesis for discrete-time stochastic systems, on distributionally robust dynamic programming using kernel methods, and on robustness of reinforcement learning algorithms. I have also studied distributed and combinatorial optimisation problems.

Over the past decades, the control community has developed powerful methods using semi-definite programming to design robust controllers. Techniques such as Youla-parametrization, Hahn-Banach type separation theorems, projection lemma, integral quadratic constraints, amongst others, combined with interior-points methods to solve semi-definite programming optimisation were at the backbone of main developments in the area. During my Masters at the University of Campinas, Brazil, I worked on how to perform robust filter design using semi-definite programming. Leveraging the generalised Kalman-Yakubovich-Popov lemma, I have developed necessary and sufficient linear matrix inequalities to perform filter design under finite-frequency specifications. It remains of interest to understand why the multipliers of these conditions need to be complex.

I joined the University of Oxford in October 2017 for a PhD, having received a very competitive scholarship from the Brazilian Ministry of Education. My PhD project built on my previous knowledge on control theory, but had a special focus on fundamental properties of optimisation algorithms. Right at the start of my PhD, I have identified an interesting research problem that is relevant to control large-scale dynamical systems with a sparse number of sensors – the industrial motivation of this problem was clear, as one usually has very few sensors to control the entire dynamics. Existing approaches focused on exploiting mathematical properties of the problem to provide optimality guarantees on the obtained selection. I have identified a problem instance that had more structure, showing that the optimal solution can be obtained exactly (not approximately) using convex relaxations. This resulted in a journal publication within the first six-months of starting my PhD.

Motivated by the previous result, I then started exploiting ways of solving large-scale optimisation problems using a collection of processing units that exchanges information by means of a communication network. The goal is to solve a centralised optimisation problem, while maintaining privacy of some core components of the problem. I have developed the analysis of an algorithm that leverages first-order information and characterised its convergence rates under weak smooth assumptions of the individual functions, which resulted in a journal publication and a paper at a top-level conference in control.

"All models are wrong, but some are useful". This quote by British statistician George Box epitomises the fact that a scientist must be careful to quantify uncertainty in mathematical model. When solving optimisation problems, this quote is also appropriate. It is not rare to encounter an optimisation under the presence of uncertain constraints. These arise when solving stochastic MPC problems with state constraints, optimal power flow problem, among others. A common approach to tackle uncertain optimisation is to employ the robust paradigm, in which the optimal solution is supposed to be feasible for any realisation of the uncertain parameters. Despite leading to safe solutions – in that all constraints will be always satisfied – the robust approach may yield overly conservative solutions. An alternative is to rely on a probabilistic viewpoint, in which constraints can be violated with a probability defined *a-priori*. In one of the my recent papers, I leveraged statistical learning tools to improve state-of-the-art bounds on the probability of constraint violation for a class of uncertain optimisation problems. A direct consequence of these results is that a decision-maker may perform a better trade-off between the performance of the obtained solution and its probability of constraint violation (in other words, they can better control the risk associated with the resulting decision). These results were published in the most prestigious journals in control and in international conferences. As a consequence of the strong contributions of my PhD thesis, I have been awarded the 2021 IET Control and Automation doctoral dissertation prize.

Machine learning and statistics applications also require uncertainty quantification. There is no shortage of examples of neural networks inputs that are misclassified after some minor perturbations. This issue must be taken seriously by the research community, especially if these networks are to be deployed in safety-critical environments. The theory used to study uncertain optimisation problems allows us to formally quantify generalisation properties of the obtained solution; unfortunately, it is elusive how to apply such a theory to neural networks. Aiming at better understanding other methods to perform uncertain quantification, and at broadening my domain of expertise, I joined the computer science department as a postdoc.

During this period as a postdoctoral research assistant, I have been studying methods for feedback controller

design. In a recent publication, which won a distinguished paper award at 2022 AAAI conference, I managed to connect formal abstraction techniques with part of the results of my PhD thesis that deal with data-driven approximations of chance-constrained problems. More recently, we have expanded the application of the previous approach to tackle uncertainty in the dynamics. Both of these papers have attracted the interest of people working with planning problems due to the way different sources of uncertainties are split. I have managed to decouple the uncertainty affecting the system's dynamics with other external disturbances and shown how this enables the use of abstraction and data-driven techniques to perform feedback controller synthesis. I have also recently explored how to generate data-driven, memory-based abstractions of dynamical systems. This is a crucial step towards applying formal verification techniques to dynamical systems, and we show preliminaries results stating that increasing the memory of the abstraction generates a better approximation of the original dynamics. Other ongoing research projects include the design of Barrier functions for stochastic systems and the solution of distributionally robust dynamic programming using kernel methods.

Broadly speaking, I am active in investigating different data-driven methods to perform feedback controller design. My recent publications show that I have been making strong contributions to the foundations of this emerging area.