UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

**DOTTORATO DI RICERCA / PHD PROGRAM IN**
**INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING**

## Activities and Publications Report

# PhD Student: Francesco De Lellis

**Student ID: DR993887**

**PhD Cycle: XXXV**
**PhD Cycle Chairman: Prof. Stefano Russo**

**PhD program student's start date: 01/11/2019**
**PhD program student's end date: 31/01/2023**

**Supervisor: Mario di Bernardo**
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**PhD scholarship funding entity: University of Napoli Federico II**

## General information

Francesco De Lellis received in year 2019 the Master Science degree in Automation Engineering from the University of Napoli Federico II. He attended a curriculum in Reinforcement Learning for Control applications within the PhD program in Information Technology and Electrical Engineering. He received a grant from University of Napoli Federico II.

## Study activities

### Attended Courses

| Year | Course Title | Type | Credits | Lecturer | Organization |
|---|---|---|---|---|---|
| 1st | Model Predictive Control | External course | 2 | Alberto Bemporad, IMT Lucca | IMT Lucca |
| 1st | Innovation management, Entrepreneurship and intellectual property | Ad hoc course | 5 | Pierlugi Rippa | ITEE |
| 1st | Statistical Learning | Msc Course | 6 | Roberta Sicliano | University of Napoli Federico II |
| 1st | Machine Learning | Ad hoc course | 3.6 | Carlo Sansone | ITEE |
| 2nd | IELTS course | External course | 5 | Thomas Geraint, Centro Linguistico di Ateneo (CLA) | Universty of Napoli Federico II |
| 2nd | Strategic Orientation for STEM Research & Writing | Ad hoc course | 4 | Chie Shin Fraser | ITEE |
| 3rd | Introduction to Reinforcement Learning and Data-Driven Control for Complex Systems | External course | 4 | Mirco Musolesi, University College London; Giovanni Russo, University of Salerno | Scuola Superiore Meridionale |
| 3rd | Corso di formazione specifica alla salute e sicurezza sui luoghi di lavoro | Ad hoc course | 2 | Centro Interdipartimentale di Ricerca Laboratorio di Urbanistica e di Pianificazione Territoriale “Raffaele d’Ambrosio” (L.U.P.T.) | University of Napoli Federico II |

### Attended PhD Schools

| Year | School title | Location | Credits | Dates | Organization |
|---|---|---|---|---|---|
| 2nd | AIRO PhD School 2021 and 5th AIRO-Young Workshop | Napoli, Italy | 3.6 | 08/02/2021 09/02/2021 10/02/2021 12/02/2021 | University of Napoli Federico II |

## Attended Seminars

| Year | Seminar Title | Credits | Lecturer | Lecturer affiliation | Organization |
|---|---|---|---|---|---|
| 1st | Deep Learning Onramp | 0.2 | Carlo Sansone | University of Napoli Federico II | ITEE |
| 1st | Lo spazio cibernetico come dominio bellico | 0.2 | Guglielmo Tamburrini | University of Napoli Federico II | ITEE |
| 1st | Additive Manifacturing: Modeling and Challenges | 0.2 | Ferdinando Auricchio | Pavia University | University of Napoli Federico II |
| 1st | Computational Biology: Large scale data analysis to understand the molecular bases of human diseases | 0.2 | Michele Ceccarelli | University of Napoli Federico II | ITEE |
| 1st | Joint Design of Optics and Post- Processing Algorithms Based on Deep Learning for Generating Advanced Imaging Features | 0.2 | Raja Giryes | Tel Aviv University | Computational Imaging Webinar Series: SPACE |
| 1st | Deep Reinforcement Learning per la risoluzione di Problemi di Controllo | 0.2 | Gianfranco Fiore | MathWorks | MathWorks |
| 1st | Large Scale Training of Deep Neural Networks | 0.2 | Giuseppe Fiameni | NVIDIA | ITEE |
| 1st | Exploring autonomy in robotic colonoscopy | 0.2 | Pietro Valdastri | University of Leeds | ITEE |
| 1st | Bias from the wild | 0.2 | Nello Cristianini | University of Bristol | Associazione italiana per la ricerca in Computer Vision, Pattern Recognition e Machine Learning |
| 1st | SINCRO Research Seminar Series | 4 | Mario di Bernardo research group | University of Napoli Federico II | University of Napoli Federico II |
| 2nd | At the Nexus of Big Data, Machine Intelligence, and Human Cognition | 0.2 | George S. Djorgovski | Caltech | Department of Physics Ettore Pancini and the Department of Electrical Engineering and Information Technology of the University Federico II in Napoli |
| 2nd | Learning-based | 0.2 | Melanie | ETH Zurich | Control Meets |

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|---|---|---|---|---|---|
| | Model Predictive Control | | Zeilinger | | Learning |
| 2nd | Reinforcement Learning Virtual School | 1.8 | | Toulouse AI institute ANITI | Toulouse AI institute ANITI |
| 2nd | The pandemic playbook, a physicist take | 0.2 | Francesco Sannino | University of Napoli Federico II | University of Napoli Federico II |
| 2nd | SINCRO Research Seminar Series | 4.2 | Mario di Bernardo research group | University of Napoli Federico II | University of Napoli Federico II |
| 3rd | Complexity and the City: transitioning towards the smart cities of the future | 0.2 | Louis Bettencourt | University of Chicago | Futuro Remoto |
| 3rd | La Scienza Oggi | 0.2 | Elena Cattaneo | University of Milan | University of Napoli Federico II |
| 3rd | Novel Opportunities in Open-Endedness | 0.2 | Kenneth O. Stanley | OpenAI | UCL Dark Seminar Series |
| 3rd | Causal foundations for safe AGI | 0.2 | Tom Everitt | DeepMind | DeepMind ELLIS UCL CSML Seminar Series |
| 3rd | MOBI UK | 1 | Mirco Musolesi | University College London (UCL) | University College London (UCL) |
| 3rd | SINCRO Research Seminar Series | 4 | Mario di Bernardo research group | University of Napoli Federico II | University of Napoli Federico II |

## Research activities

**Title**: Tutoring Reinforcement Learning via Feedback Control
**Description**: Francesco De Lellis has been conducting research on Control-Tutored strategies for Reinforcement Learning (CT), namely Control-Tutored Reinforcement Learning (CTRL), for the control of uncertain dynamical systems. The aim of the research is to find out if nonlinear control strategies can be used in combination with RL algorithms to improve data efficiency, lower learning times and improve the controller performance and robustness. During this year two main algorithms have been designed, the Control-Tutored Q-Learning (CTQL) algorithm and Control-Tutored Deep Q-Learning (CTDQL) along their probabilistic counterparts pCTQL and pCTDQL. These strategies make use of a control policy to improve the learning phase of the Q-learning algorithm [6] by using a control law to recommended possible control actions based on a partial knowledge of the system dynamics. Such element is encoded in a mathematical model that describes the environment on a basic level. During the research Francesco De Lellis has been testing such proposed strategies on the following benchmark problems

1. The multi-agent herding problem, where one or more agents have to collect and contain a group of target agents.
2. The classical benchmark of stabilizing an inverted pendulum as posed in OpenAI gym.
3. The problem of Landing a Spacecraft on an unknown surface as posed in OpenAI gym LunarLander environment
4. The autonomous driving problem as posed in as posed in OpenAI gym CarRacing environment

In those cases, the proposed strategies showed their capability of drastically reducing learning times, improving data efficiency and achieving satisfactory results with the use of basic and partial model of the environments considered. This further pushed the research towards the search of a unified framework for the control of dynamical systems that makes uses of state of the art Reinforcement Learning techniques in combination with nonlinear control laws to face the need of dealing with very uncertain modelling of the system dynamics.
Lastly, a study of the convergence properties of such strategy have been analysed using results present in the literature to link the classical tabular Q-learning proof of convergence with the tabular version of the CTQL algorithm.

**Collaboration**: Marco Coraggio [1,2], Giovanni Russo [3], Mirco Musolesi [4] and Mario di Bernardo [1,2]
[1] (University of Naples Federico II)
[2] (Scuola Superiore Meridionale)
[3] (University of Salerno)
[4] (University College London)

**Title**: Modelling and control of pandemics via non pharmaceutical measures
**Description**: Francesco De Lellis also worked on deriving a model of Italy as a network of regions to capture the COVID-19 epidemic. This work showed how decisions taken at the regional level can make a huge impact on the containment of the epidemic and economic costs. The strategies proposed acted on this model with a simple bang-bang control strategy based on the current number of intensive care units in use at the regional level. The results showed that a localized intermittent lockdown strategy brings substantial advantages compared to an aggregate national lockdown measure. Despite being accurate as a model, several discrepancies exist with the actual epidemic dynamics. So current research aims at checking if the trivial bang-bang control strategy can be assisted by a reinforcement learning algorithm to find better control solutions that could potentially bring robustness to unmodeled dynamics.

**Collaboration**: Fabio Della Rossa [3], Davide Salzano [1], Anna Di Meglio [1], Marco Coraggio [1], Carmela Calabrese [1], Agostino Guarino [1], Ricardo Cardona-Rivera [1], Pietro De Lellis [1], Davide Liuzza [4], Francesco Lo Iudice [1], Giovanni Russo [2] and Mario di Bernardo [1]
[1] (University of Naples Federico II)
[2] (University of Salerno)
[3] (Polytechnic of Milan)
[4] (ENEA)

## Tutoring and supplementary teaching activities

Francesco De Lellis co-supervisor of the thesis of 4 master students in *Ingegneria dell'Automazione* ad assisted the students weekly with about 2 hours tutorship ("ricevimento") for the course of *Dinamica e Controllo Non Lineare* in *Ingegneria dell'Automazione*.

### Credits summary

| PhD Year | Courses | Seminars | Research | Tutoring / Supplementary Teaching |
|---|---|---|---|---|
| 1st | 16.6 | 5.8 | 35 | 1 |
| 2nd | 12.6 | 6.6 | 45 | 1 |
| 3rd | 6 | 5.8 | 60 | 1 |

## Research periods in institutions abroad and/or in companies

| PhD Year | Institution / Company | Hosting tutor | Period | Activities |
|---|---|---|---|---|
| 2nd | University College Dublin (UCD) | Giovanni Russo, Associate Professor | 12/01 – 12/02/2021 | Research on Q-learning<br>Lab experiments on Control-Tutored Q-learning<br>Joint scientific paper preparation and publication |
| 3rd | University College London | Mirco Musolesi, Full Professor | 26/5/2022-17/6/2022<br><br>27/06/2022-04/09/2022 | Research on Deep Q-Learning and Neural Networks<br>Lab experiments on pCTDQL for the solution of OpenAI's LunarLander benchmark problem<br>Joint scientific paper preparation and publication |

## PhD Thesis

In its PhD Thesis, Francesco De Lellis is going to show novel approaches to apply Reinforcement Learning (RL) to control problems. RL provides a set of powerful methods that can be used to train artificial agents to solve control problems without requiring a mathematical model of the system dynamics. This is particularly relevant to the field of control since, in many applications, the lack of a complete model description can lead to unsatisfactory performance of classical model-based control. On the other hand, RL can solve such problems, since a controller can be trained with data to learn how to correctly solve a given control problem. The main disadvantage of RL algorithms is that they require long learning times and typically huge datasets. This fact is the main brake to the mass adoption of RL for control problems. In this thesis, novel approaches to combine partial modelling with model-free RL are going to be discussed. The aim is to solve control problems using only partial information in combination to RL thus reducing learning times and data needed to train such controllers. Also, Francesco is going to investigate how to design a reward function to give a certificate of stability and performance in terms of control metrics (e.g. settling time and steady state error) to the final learned controller via RL. Finally, to show the advantages and drawbacks of the proposed control strategies based on RL, the OpenAI gym suite is going to be used for benchmarking.

## Publications

Research results appear in *1* paper published in international journals and *3* contributions to international conferences.

## List of scientific publications

### International journal papers

F. Della Rossa, D. Salzano, A. Di Meglio, F. De Lellis, M. Coraggio, C. Calabrese, A. Guarino, R. Cardona-Rivera, P. De Lellis, D. Liuzza, F. Lo Iudice, G. Russo, M. di Bernardo,
A network model of Italy shows that intermittent regional strategies can alleviate the COVID-19 epidemic,
*Nature Communications*, vol. 11, 5106, 2020, DOI: 10.1038/s41467-020-18827-5.

### International conference papers

F. De Lellis, G. Russo, M. di Bernardo,
Tutoring Reinforcement Learning via Feedback Control,
*IEEE European Control Conference (ECC),*
Delft, Netherlands, 29 June - 2 July 2021, pp. 580-585, IEEE, DOI: 10.23919/ECC54610.2021.9654881

F. De Lellis, F. Auletta, G. Russo, P. De Lellis, M. di Bernardo,
An Application of Control-Tutored Reinforcement Learning to the Herding Problem,
*IEEE International Workshop on Cellular Nanoscale Networks and their Applications*, Catania, Italy, 29 September - 01 October 2021, pp. 1-4, IEEE, DOI: 10.1109/CNNA49188.2021.9610789.

M. Coraggio, S. Xie, F. De Lellis, G. Russo, M. di Bernardo,
Intermittent non-pharmaceutical strategies to mitigate the COVID-19 epidemic in a network model of Italy via constrained optimization,
*IEEE Conference on Decision and Control (CDC),*
Austin, Texas (US), 13 - 17 December 2021, pp. 3538-3543, IEEE, DOI: 10.1109/CDC45484.2021.9683420

F. De Lellis, M. Coraggio, G. Russo, M. Musolesi, M. di Bernardo,
Control-Tutored Reinforcement Learning: Towards the Integration of Data-Driven and Model Based Control
*Learning for Dynamics and Control Conference (L4DC),*
Stanford University, California (US), 23 - 24 June 2022,pp. 1048-1059, PLMR,
https://proceedings.mlr.press/v168/lellis22a/lellis22a.pdf

**Date** 19/12/2022

**PhD student signature** Francesco De Lellis

**Supervisor signature**