FINAL REPORT

Student name: Chiara Favaretto
Cycle: XXX
Curriculum: ICT
Supervisor name: Prof. Angelo Cenedese
Thesis title (final): Population models for complex non-linear phenomena: from mitochondrial dynamics to brain networks.

PART 1 - COURSES, CONFERENCES AND MOBILITY

Courses for Ph.D. students

- Mathematical modeling of cell biology (Prof. *Mortem Gram Pedersen*)
- Applied Linear Algebra (Prof. *Giorgio Picci*)
- Statistical Methods (Prof. *Lorenzo Finesso*)
- Applied Functional Analysis (Prof. *Gianluigi Pillonetto*)

Summer schools, short courses, tutorials

- **EECI Course**: *Nonlinear control for physical systems* (Berlin, 23 - 27/03/2015)
- **SIDRA PhD Summer School**: *Robot Control & Underwater Robotics* (Bertinoro, 13 - 18/07/2015)

Seminars

First Year:

1. 13/11/14: Florian Dörfler, *ETH Zürich*
   "Plug and Play Operation of Microgrids", Automatica Group Seminars
2. 14/11/14: Josè A. Cobos, *Technical Univ. Madrid*
   "Power Supply Systems for Energy Efficiency", DEI Distinguished Lecture
3. 17/11/14: Arthur Krener, *Univ. California Davis*
   "Filtering of Boundary Value Discrete Time Linear Systems", Automatica Group Seminars
4. 27/11/14: Luigi Colangeli, *European Space Agency (ESA)*
   "Rosetta rendez-vous with the 67P/Churyumov-Gerasimenko comet", DEI Distinguished Lecture
5. 13/03/15: Michele Pavon, *Univ. Padova*
   "On the geometry of maximum entropy problems", Automatica Group Seminars

6. 23/03/15: Walter Snoeys, *PH department, CERN*
   "How chips helped discover the Higgs boson at CERN", DEI Distinguished Lecture

7. 08/04/15: Ulrich Oberst, *Univ. Innsbruck*
   "Weakly exponentially stable linear time-varying differential behaviors", Automatica Group Seminars

8. 20/04/14: Keshav Pingali, *Univ. Austin*
   "Kinetic Dependence Graphs", Informatics Group Seminars

9. 24/04/15: Luigi Palopoli, *Univ. Trento*
   "When multimedia meets control: use of soft real-time techniques for control design", Automatica Group Seminars

10. 29/04/15: Gianluca Pollastri, *UC Dublino*
    "Deep architectures and deep learning in chemoinformatics: the prediction of properties and activities of drug-like molecules", Informatics Group Seminars

11. 29/05/15: Tryphon T. Georgiou, *Univ. Minnesota*
    "The Hilbert metric and Schrödinger bridges", Workshop: New challengès in reciprocal processes, Schrödinger bridges...

12. 29/05/15: Markus Fischer, *Univ. Padova*
    "On large deviations for the empirical measures of weakly interacting systems", Workshop: New challenges in reciprocal processes, Schrödinger bridges...

13. 29/05/15: Francesco Ticozzi, *Univ. Padova*
    "A walk to symmetrization via a Schrödinger bridge", Workshop: New challenges in reciprocal processes, Schrödinger bridges...

14. 03/06/15: Mérouane Debbah, *Huawei France R&D Center*
    "Mathematical Scientific Challenges of 5G", DEI Distinguished Lecture

15. 17/06/15: Michel Verhaegen, *Univ. Delft*
    "Nuclear Norm identification for lumped and distributed systems", Automatica Group Seminars

16. 18/06/15: Rodolphe Sepulchre, *Univ. Cambridge*
    "Do brains compute?", DEI Distinguished Lecture

17. 07/07/15: Davide Piovesan, *Univ. Gannon*
    "Human Arm Mechanics: from system identification to neural control", DEI Colloquia

18. 09/07/15: Luca Scardovi, *Univ. Toronto*
    "From Synchronization Analysis to Synchronization Control of Cellular Networks", Automatica Group Seminars

19. 25/09/15: Pratap Pattnaik, *IBM*
    "Bitcoin, an attempt at a separation of money and state", DEI Distinguished Lecture

20. 28/09/15: Balz Zupan, *Univ. Ljubljana*
    "Large-scale data fusion", Bioengeneering Group Seminars

21. 30/09/15: Crescenzi, *Univ. Firenze*
    "Fast and Simple Computation of Top-k Closeness Centralities", Informatics Group Seminars

22. 30/10/15: Giulio Caravagna, *Univ. Edinburgh*
    "Algorithmic Methods to Infer the Evolutionary Trajectories in Cancer Progression", Bioengeneering Group Seminars

Second Year:

1. 02/02/16: Marco Zorzi, Giovanni Sparacino, Luca Tonin, Giulia Cisotto, Alessandra Bertoldo, Maurizio Corbetta, *Univ. Padova, Washington University (St Louis)*
   "Neuroscience Day @ Dei", Workshop

2. 22/03/16: Maurizio Corbetta, *Washington School of St. Louis*
   "Spontaneous brain activity in health and disease", VIMM Lecture

3. 01/04/2016: Lucia Pallottino, *Univ. Pisa*
   "The Walk-Man humanoid robot: whole-body loco-manipulation planning and control", Automatica Group Seminars

4. 25/04/16: Paulo Tabuada, *UCLA*
   "Secure state-estimation and control for dynamical systems under adversarial attacks", UCR EM Seminar

5. 20/09/2016: Yanzhi Wang, *Syracuse University*
   "Deep Neural Network and Deep Reinforcement Learning: Ultra-Low Energy Implementation and Broad Applications", UCR EM Seminar

Third Year:

1. 31/01/2017: Ilaria Mazzonetto, *Univ. Padova*
   "To what extent does the EEG montage density impact on the accuracy of source localization?", V.I.M.M. Seminars

2. 14/02/2017: Claudia Lodovichi, *V.I.M.M.*
   "Circuit formation and function in the olfactory system", V.I.M.M. Seminars

3. 28/02/2017: Sandro Zampieri, *Univ. Padova*
   "Information transmission in balanced neuronal networks: the role of matrix non-normality", V.I.M.M. Seminars

4. 02/03/2017: Andrea Brovelli, *Institut de Neurosciences de la Timone (Marseille)*
   "Functional Connectivity Dynamics using high-gamma MEG activity", V.I.M.M. Seminar

5. 05-26/04, 17-31/05/2017: Giulia Prando, *Univ. Padova*
   "Deep Learning", Automatica Group Seminars

6. 21/04/2017: Paolo Ferragina, *Univ. Pisa*
   "PhD+: research valorization, innovation and entrepreneurial mindset", DEI Seminars

7. 03/05/2017: John Hauser, *Univ. Colorado at Boulder*
   "Trajectory Exploration for Aggressive Maneuvering", Automatica Group Seminars

8. 12/05/2017: Alberto Sangiovanni Vincentelli, *Univ. Berkeley (CA)*
   "Is Technology Transfer a Dream or a Reality?", Distinguished Lectures

9. 18/05/2017: Giulio Tononi, *Univ. Wisconsin, Madison*
   "Consciousness: From Theory to Practice", Distinguished Lectures

10. 31/05/2017: Giacomo Baggio, *Univ. Padova*
    "The influence of network structure in neuronal information transmission", Mathematica Group Seminars

11. 07/06/2017: Stefano Vassanelli, *Univ. Padova*
"Connecting brain and artificial neural networks with memristive synapses: a tale from the RAMP project", V.I.M.M. Seminars

12. 09/06/2017: Francesca Boem, *Imperial College, London*
"Scalable Methods for Fault-tolerant Control of Large-Scale Systems", Automatica Group Seminars

13. 21/06/2017: Reza Arghandeh, *Florida State University*
"From Data Mining to Knowledge Mining in Smart Infrastructure", Automatica Group Seminars

14. 21/06/2017: Mattia Zorzi, *Univ. Padova*
"Sparse plus low rank network identification: A nonparametric approach", Automatica Group Seminars

15. 23/06/2017: Marco Todescato, *Univ. Padova*
"Efficient Space/Time Learning: Gaussian Regression meets Kalman Filtering", Automatica Group Seminars

16. 04/07/2017: Angelo Antonini, *Univ. Padova*
"Alterazioni molecolari e funzionali nella Malattia di Parkinson e loro approccio terapeutico", Inaugural Lecture

17. 22/09/2017: Chris Van Hoof, *Holts Centre / IMEC, The Netherlands*
"Personal Behavioral Technology - Wearables Can Become an Active Contributor to Your Wellbeing", Distinguished Lectures

Participation to International Conferences and Workshops

- 14th IFAC Symposium on Large Scale Complex Systems: theory and Applicationts (UCR, CA, USA, 28/05/16)
- 30th Southern California Control Workshop (UCSD, CA, USA, 03/06/2016)
- 31th Southern California Control Workshop (UCI, CA, USA, 21/10/2016)
- CDC Workshop: *Dynamics and Control in Social Networks* (Las Vegas, USA, 11/12/2016)
- 55th IEEE Conference on Decision and Control (CDC 2016) (Las Vegas, USA, 12-14/12/2016)
- 2017 American Control Conference (ACC 2017) (Seattle, WA, USA, 24-26/05/2017)

Other learning activities

- Padova Neuroscience Center Course: *Introduction to Resting State fMRI Processing* (Nicholas Metcalf, B.S. Bioinformaticist and Data Analyst at Washington University in St. Louis) (18-26/09/2017)
- Tutor Junior activities:
  1. course of *System and models* for the third year of Information Engineering (2015-2016)
  2. *Educational tutoring (Tutorato Formativo)* for the first year of Biomedical Engineering (2015-2016)
  3. course of *Mathematica* for the first year of CTF (2015-2016)
  4. course of *Laboratory of Automatica* for the third year of Information Engineering (2016-2017)

5. Tutor Juniors' coordinator (2016-2017).

Mobility periods

Dates: April 12th - July 29, 2016 & September 13th - December 21st, 2016

Hosting institution: University of California, Riverside (UCR) (Prof. *Elisa Franco* & Prof. *Fabio Pasqualetti*)

Title of the activity: Mathematical modeling of mitochondrial population dynamics and analysis, models and control of networks of neurons.

Summary of Visits and Collaborations

1. visit to the laboratory of Prof. *Maurizio Corbetta* at the Washington University of St Louis (Missouri), with whom I have started a collaboration on brain networks;
2. visit to the laboratory of Prof. *Mochly-Rosen* (Stanford University, Dep. of Medicine), with whom I have started a collaboration to model the mitochondrial dynamics;
3. collaboration with the laboratory of Prof. *Danielle Smith Bassett* (University of Pennsylvania).

PART 2 - RESEARCH ACTIVITY

Synchronization: The problem of emergent synchronization patterns in a complex network of coupled oscillators has caught scientists' interest in a lot of different disciplines. Specifically, we considered an extended version of the Kuramoto model, a classical model apt to describe oscillators' dynamics, and we quantified how the intrinsic features of the oscillators and their interconnection paramenters affect the formation and the stability of clustered configurations. In doing it we exploited both linear and nonlinear tools of system theory. Finally, we defined a control law, in order to reach a clustered configuration in a network of Kuramoto oscillators with some structural contraints, which limit the selection of edges that can be modified.

Mitochondrial Dynamics: Being the main atp producers in human cells, mitochondria together with their dynamics have been the research object of a number of scientists over the past decade and although the main phenomena that characterize the mitochondria functions have been studied and described in the literature, a lot of questions have still to be answered. In particular, despite the fact that it is agreed that a link between the atp and the mitochondrial life cycle should exists, very little attention have been posed in taking into account the production of the atp by mitochondria and the request of energy from the cell in the mathematical models proposed to describe the mitochondrial dynamics. Nonetheless, this would represent an important (if not fundamental) regulation loop within the whole mitochondrial dynamics. The objective of our reaserch has been focused to propose a mathematical model that is simple enough to be descriptive and consistent with intuition, and meanwhile sufficiently complex to include the main phenomena that qualitatively characterize the whole dynamics.

Brain Networks: Considerable attention has been recently devoted to the study of the human brain as a network of different cortical regions that show coherent activity during resting-state. In literature, there can be found different large-scale models of resting-state dynamics in health and disease. During our research, we combined our theoretical results

about synchronization to compare an extended version of the Kuramoto model with other models used in literature (Rulkov neuron model, FitzHugh-Nagumo model, Greenberg-Hastings model), in order to simulate the dynamics of networks of brain areas in resting-state and predict the functional connectivity matrix through the structural connectivity one. Then, we are collaborating with the University of Chieti in a project aimed to analyze and compare fMRI and MEG data recorded during a specific visual-attentional task. Thanks to this project I joined the Padova Neuroscience Center, istituted by Professor *Corbetta*.

PART 3 - PUBLICATIONS

If not yet published, please indicate the publication status (submitted, accepted)

List of publications on conference proceedings

C1. A. Cenedese, C. Favaretto. On the synchronization of spatially coupled oscillators. 54th Conference on Decision and Control (CDC15), pp. 4836–4841, 2015.

C2. C. Favaretto, A. Cenedese. On brain modeling in resting-state as a network of coupled oscillators. 55th Conference on Decision and Control (CDC16), pp. 4190-4195, 2016.

C3. A. Cenedese, C. Favaretto, G. Occioni. Multi-agent Swarm Control through Kuramoto Modeling. 55th Conference on Decision and Control (CDC16), pp. 1820-1825, 2016.

C4. C. Favaretto, D.S. Bassett, A. Cenedese, F. Pasqualetti. Bode meets Kuramoto: Synchronized Clusters in Oscillatory Networks. 2017 American Control Conference (ACC), pp. 2799-2804, 2017.

C5. C. Favaretto, A. Cenedese, F. Pasqualetti. Cluster Synchronization in Networks of Kuramoto Oscillators. IFAC 2017 World Congress, pp. 2485–2490, 2017.

C6. L. Tiberi, C. Favaretto, M. Innocenti, D.S. Bassett, F. Pasqualetti. Synchronization Patterns in Networks of Kuramoto Oscillators: A Geometric Approach for Analysis and Control. 56th IEEE Conference on Decision and Control - [accepted], 2017.

C7. F. Pasqualetti, C. Favaretto, S. Zhao, S. Zampieri. Fragility and Controllability Tradeoff in Complex Networks. 2018 American Control Conference (ACC) - [submitted], 2018.

Padova, 28/09/2017

Student signature

Chiara Favaretto

Supervisor signature

Angela Cenedese