PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Carmela Calabrese

XXXIII Cycle

Training and Research Activities Report – First Year

Tutor: Mario di Bernardo – co-Tutor: Benoit G. Bardy, Pietro De Lellis

Università degli Studi di Napoli
FEDERICO II

a. Information

I got a M. Sc. degree cum laude in Control engineering on the 2nd October 2017 at the University of Naples- Federico II. My master thesis focused on the development and analysis of a non-linear mathematical model for intra- and inter-brains synchronization during human interactions. Part of this work was carried out in collaboration with the University of Bristol, UK, under the supervision of professor Mario di Bernardo (Naples) and professor Naoki Masuda (Bristol).

In January 2018 I won a PhD scholarship (XXXIII cycle) under "Vinci Programme 2017" at the ITEE-University of Naples. I am enrolled in a joint PhD programme between the University of Naples-Federico II and Université de Montpellier, supervised by professors Mario di Bernardo (Naples), Benoit G. Bardy (Montpellier), and Pietro De Lellis (Naples).

b. Study and Training activities

a. Courses

i. *Analisi e Controllo di Reti Complesse (6 CFU)*
Lecturer: Professor P. De Lellis

ii. *Delay differential equations (DDEs) and their application (3 CFU)*
Lecturer: Professor J. Hogan

iii. *Introduction to modelling and control of mechanical systems with constraints (2 CFU)*
Lecturer: Professor A. Shiriaev

iv. *How to public a scientific paper (0.4 CFU)*
Lecturer: Dr. A. Birukou & E. Magistrelli

b. Seminars

i. *Tecnologie digitali e scienze umane- Internet e Intelligenza artificiale: ordine spontaneo o regolato?*
Lecturer: R. Bifulco & G. Ventre- Date: 12/01/18- 3h

ii. *Tecnologie digitali e scienze umane- Etica e intelligenze artificiali*
Lecturer: G. Tamburrini & R. Bodei- Date: 01/02/18- 2.5h

iii. *Tecnologie digitali e scienze umane- Le nuove frontiere della robotica cognitiva e l'interazione uomo- robot*
Lecturer: A. Finzi & B. Henry- Date: 23/02/18- 2.5h

iv. *Tecnologie digitali e scienze umane- Razionalità limitata nell'uomo e nella macchina*
Lecturer: L. Sauro & M. Ferraris- Date: 16/03/18- 3h

v. *Tecnologie digitali e scienze umane- Lasciamo parlare i dati: riflessioni sull'apprendimento automatico e i big data*
Lecturer: A. Corazza & G. Roncaglia: Date: 13/04/18- 3h

vi. *Tecnologie digitali e scienze umane- Internet, Intelligenza artificiale e tutela della privacy*
Lecturer: P. A. Bonatti & G. Buttarelli- Date: 11/05/18- 3h

vii. *Enabling the Innovators and Entrepreneurs of Tomorrow*
Lecturer: Professor X. Xi & Mr. W. Jian- Date: 17/04/18- 2h

viii. *Approssimazioni di problemi alle derivate parziali e applicazioni*
Lecturer: Professor A. Quarteroni- Date: 11/05/18- 5h

ix. *How does MathWorks accelerate the pace engineering and science?*
Lecturer: PhD F. Alderisio- Date: 01/06/18- 1h

x. *From engineering to mathematics (and the other way round): two nonlinear case-studies*
Lecturer: Professor J. M. Olm- Date: 05/06/18- 3h

xi. *Discovering the network topology of complex systems*
Lecturer: PhD D. A. Burbano-L.- Date: 05/06/18- 1h

xii. *The Napoli Federico II IEEE student branch*
Lecturer: Ing. S. Marrone- Date: 17/07/18- 1h

xiii. *Wearable systems: design and implementation challenges*
Lecturer: Professor M. Ghassemian- Date: 17/09/18- 2h

xiv. *Domains of attraction and manifolds in a gear model*
Lecturer: Professor P. Piiroinen- Date: 05/11/18- 1h

c. External courses

i. *La recherché européenne et les financement post-doctoraux (3 CFU)*
Lecturer: Professor B. G. Bardy- Date: 13-14/12/18

c. Research activity

a. Title

Analysis and control of leadership emergence and human group synchronization.

b. Research description

Human beings have evolved as group-living animals and, as every group, they developed a status hierarchy: there are people at the bottom, in the middle, and at the top, and everyone knows who is where. Leadership research in Human Sciences has shed light on the personality traits that promote the emergence of a leader and how this process comes out. It is possible to find several definitions of leadership [1, 2] but they focus only on isolated variables that describe some specific aspects that characterize a leader. Elaborating an integrative definition of leadership encompassing all of them is a challenging goal [1]. Leadership is usually defined in terms of the people who are in charge of organizations and their units; by definition, such people are leaders. But people who rise to the tops of large organizations are distinguished by hard work, intelligence, ambition but not necessarily by talent for leadership. Leadership involves persuading people to set aside, for a time, their self-interests and work in support of the common interest. In this way, a leader in a team can be thought as the person who selects, trains, and **influences** one or more followers with different abilities and guides them to enthusiastically expend energy to achieve goals. In this sense, personality- how a person thinks about her-/himself (i.e., a person's identity) and how others think about that person (i.e., a person's reputation)- predicts leadership: **who we are is how we lead.**

A part of literature rejects a person-centric and hierarchical approach to the study of leadership where supervisors are leaders, subordinates are followers, and these *leader-follower identities* are **static**. It is limiting because it does not fully take into account for the social interactions and reciprocal influence patterns that **enable *leading-following relationships* to develop and evolve over time** [3], such that the direction of influence in *leading-following interactions* can move up and down [4]. Many works agree that leadership is a **collective phenomenon** and that a more social and dynamic conception of *leading-following* ***processes*** in groups is needed- individuals are involved in repeated *leading-following interactions*, and through these, **they co-construct identities as leaders and followers**. Over time through repeated interactions, these *leader-follower relationships* emerge to form group-level leadership structures that range from centralized to shared patterns of leading and following that can evolve in ways to enable groups to adapt in dynamic contexts [5]. This **adaptivity** is supported by a collective process of **learning** that change reputation relationships among the agents- how this changes with experience impacts on the influence structure of the group network [6]. In fact, literature on applause [7], on motor joint coordination [8] and results on joint performances [9] have highlighted the dynamic nature of human interactions: agents build their own preferred attachments over time and adjust each other and to a varying environment. This adaptive process requires **plasticity** in human behaviour- in order to cooperate people are willing, to a different degree, to disregard their individual preferences. For this reason, it is important to focus on how coordination among agents and leadership affect these dynamics, to discover the principles behind motor coordination and how similarity among agents fosters synchronization.

There are several examples in the animal and human world where collective behaviour dynamics occur. Social animals that forage or travel in groups have to make a multitude of group decisions involving coordination of activities and travel directions. These decisions in groups of insects, birds and fish cannot be fully understood in terms of simple individuals alone but it is important to take into account how social information is integrated or other factors as *positive feedback* or *response thresholds*, that are repeatedly observed in very different animal societies [10]. In many cases, few individuals have relevant information, such as knowledge about the location of a food source or of a migration route [11] whereas, in other cases, achieving collective group action may not be accomplished by simple rules alone and it could require the averaging of preferences (democracy) or following the choices of specific leaders (despotism) [12]. The daily situations where examples of human coordination arise are varied and generally too complex to reveal basic processes of entrainment and to understand group dynamics and leadership emergence. For this reason, interpersonal coordination is mainly investigated in simple contexts. Complex science has primarily looked at dyadic interactions ([13, 14, 15]) or, on the other extreme side, at crowds ([14, 16]). In literature there are very few examples about motor interactions in groups with countable numbers of agents, as [14, 65].and, in addition, they do not completely focus on motion, synchronization and leadership. Coordination has not yet been studied in details because one of the problems is that researchers have little control over the participants' characteristics and strategies that affect their interactive behavior, and that may be difficult to not take into account- like social influence due to visual and auditory coupling. One promising approach, as a preliminary step toward investigating motor synchronization among individuals, is to study cooperation of participants through platforms that simulate the potential behavior of a human partner in the task [13, 15]. This approach makes it possible to control and vary systematically the simulated partner's characteristics, so that there is only one unknown set of parameters and strategies that needs to be inferred from the data.

Complexity theory is a powerful tool to analyse and model human behaviour in groups of agents cooperating and exchanging information **without coordination from a central controller**.

Complexity theory is the science of interacting agents- it explores the nature of interaction and adaptation in such systems and how they allow the emergence of particular dynamics like **consensus** or **synchronization**. As previously anticipated, human behaviour and interactions can be analysed through a **network framework**, looking at *leadership as an ensemble of behaviors and processes that influence dynamics and interconnectivity*.

The structure and dynamics of animal societies can be described through a **network framework** [17] where individuals are represented by **nodes** and the **edges** model the social links. In particular, these interactions are typically **multi-dimensional** and, therefore, sometimes standard network approaches are not sufficient since they do not take into account such *heterogeneities*. They can be modeled and analysed through new tools arising in network science, that is **multilayer networks**, where multiple interconnected layers are associated to different and simultaneous dynamical processes [17].

First attempts to model human group interaction can be found in [13, 15, 16]. In these works, researchers followed a bottom-up approach to build experiment-driven models were each agent was modelled by incorporating control laws based on the information that regulates each behaviour or considering error correction terms that can be modulated by intentions and context. There is an interesting example of application to group synchronization where researchers revealed some features of the rhythmic applause, describing the phenomenon through a population of nonidentical rotators globally coupled, that is the **Kuramoto's model** [18]. It has been widely used in synchronization literature. In particular, Ha et al. [19] described complete synchronization of Kuramoto oscillators connected through **hierarchical leadership topology**. Therefore, leadership is structurally injected in the model and not described as an emergent feature. In fact, the main problem of the theoretical approaches to leadership is that researchers always define leaders as agents with particular features in dynamics (already embedded) and not with emergent characteristics. This is, for example, the case of [20] where two definitions of possible leaders were introduced: **power** *(where to go*) and **knowledge leaders** *(how to go)*.

The main goal of this project is, therefore, the development of a new theory on human group motor synchronization and leadership emergence. The analysis and understanding of human coordination dynamics will help to infer the best model able to capture what happens when we synchronize our motion in group. To this end, in December 2017 we run a set of pilot experiments in the labs of the University of Naples- Federico II. The goal of this work was to analyse the interactions of a group of participants playing the paradigmatic mirror game [21] through a hardware/software platform developed in Naples, *Chronos* [22]. This setup allows to cut off any visual and acoustic coupling among the players. This choice was made to ensure that any measure, result and conclusion could be independent from any social influence during the interaction and to study the real nature of motor group synchronization.

Five participants- 4 males and 1 female, all right handed- took part to the experiments. They were recruited among students of University of Naples- Federico II. They were asked to perform two-day sessions, separated by one week:

- <u>Session 1:</u> we captured the individual behavioural repertoire (solo condition), asking each participant to sit comfortably on a chair and create sinusoidal motion by moving her/his preferred hand above a Leap Motion sensor[ref] connected to a laptop. The movement of a participant was visualized on the screen of the laptop as a dot by means of the software *Chronos*. Participants were given the following instruction: *'Play the game on your own natural frequency'*.

- Session 2: we tested the group condition where participants sat comfortably and interacted through *Chronos*, without seeing each other and acoustically isolated by means of headphones playing white noise. Participants were instructed to move their preferred hand above a Leap Motion sensor, with the instruction: *'Imitate each other and create synchronized and interesting motion. Enjoy playing together'*. Four regular topologies were considered: complete, ring, path, star.

From preliminary data analyses, we made some interesting observations about human group synchronization. Specifically, we noticed that

1. the synchronization frequency reached by participants in group was smaller than the average of the natural frequencies exhibited by players in solo condition;
2. the configuration of people in a given topology influenced the quality of phase synchronization, which was evaluated by computing the order parameter [23];
3. leadership- in terms of influence, which was evaluated by computing causation entropy [24]- was not an intrinsic characteristic of the participants but it was distributed among the players and across the trials. It also emerged that in most cases (43 out out the 49 trials) the most influencing player during a trial was the one leading in phase for the biggest or smallest fraction of time.

Our next goal will be to confirm these findings on new datasets that will be collected (February 2019) at the EuroMov Center in Montpellier, with the support of professor Benoit G. Bardy, expert in experimental motor studies. Then, leveraging the results of the data analyses, we will seek for new mathematical model capable of reproducing the behaviour of the players and their coordination.

Once the data analyses and modelling phases are completed, a further step is to move to control design. The idea is to build a Virtual Player (VP) able to gain leadership and steer the human group towards a preferred behaviour. This turns out to be relevant, for instance, if we think of application regarding the rehabilitation of social disorders, such as, for instance, autism spectrum disorders, which affects around 1% of adult population.

Bibliography

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d. Products

a. Publications (in preparation):

- *i.* M. di Bernardo, B. G. Bardy, P. De Lellis, C. Calabrese, *"Leadership emergence: insights on the way we interact"*
- ii. B. G. Bardy, M. di Bernardo, P. De Lellis, S. Bourgeaud, C. Colomer, C. Calabrese, "*Volontary and spontaneous group motor synchronization through pendula*"
- iii. M. di Bernardo, B. G. Bardy, P. De Lellis, Bosselut G., C. Calabrese, "*Leadership review: a pathway from Human Sciences to Complex Systems*"

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e. Conferences and Seminars

a. Weekly participation to internal lab meetings (2 hours) of SINCRO group research

b. Organization and participation to the workshops:

"*Control of synchronization between human and artificial agents for autism rehabilitation through group interactions*" (VINCI project), in Naples;

"*Analysis of synchronization between humans during group interactions: research update*" (VINCI project), in Montpellier.

c. Presentations made

"*13th SICC Tutorial Workshop "Topics in Nonlinear Dynamics" on "Complexity and the City*"- Torino (Italy), 29th-30th October 2018

d. Future (intentional) presentations

"*International Conference on Perception and Action (ICPA)"*- Groningen (Netherlands), 3rd-6th July 2019

"8th Joint Action Meeting (JAM)"- Genova (Italy), 10th-13th July 2019

f. Activity abroad

a. Brief visiting periods for scientific update and training at the EuroMov Centre, Université de Montpellier: 14th-21st October 2018 and 9th-15th December 2018.

b. Future brief visiting period for research activity (running experiments) at the EuroMov Centre, Université de Montpellier: 3rd-9th February 2019.

c. Future visiting period as planned by the joint program signed by the University of Naples and by the University of Montpellier: 1st April 2019- 31st July 2019.

g. Tutorship

a. Assistant for one lesson of the M.Sc. course "Analysis and Control of complex systems" (Cod. U1157) held by the researcher Pietro De Lellis.
b. Assistant for exercises of the M.Sc. course "Identification and Optimal Control" (Cod. U1954- Ingegneria dell'Automazione) held by professor Francesco Garofalo.
c. Assistant for exercises of the M.Sc. course "Model identification and Optimal Control" (Cod. 17131- Ingegneria dell'Automazione) held by professor Francesco Garofalo.
d. Weekly 2 hours tutorship (ricevimento) for the courses "Identification and Optimal Control" (Cod. U1954- Ingegneria dell'Automazione) and "Model identification and Optimal Control" (Cod. 17131- Ingegneria Gestionale).

Student: **Carmela Calabrese** carmela.calabrese@unina.it

Tutor: Mario di Bernardo mario.dibernardo@unina.it

Cycle XXXIII

									Credits year 2									**Credits year 3**									
	1	2	3	4	5	6			1	2	3	4	5	6			1	2	3	4	5	6			
	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	**Estimated**	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	**Estimated**	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	**Total**	**Check**
Modules	0	0	6	5	0	3.4	**14.4**	**15**	5						**0**	**5**							**0**	**10.9**	**30-70**
Seminars	1.6	1.6	2.6	0.2	0.2	0.2	**6.4**	**5**							**0**	**4**							**0**	**3.6**	**10-30**
Research	8.4	8.4	1.4	4.8	9.8	6.4	**39.2**	**43**							**0**	**53**							**0**	**39,5**	**80-140**
	10	10	10	10	10	10	**60**	**60**	0	0	0	0	0	0	**0**	**0**	0	0	0	0	0	0	**0**	**60**	**180**