Catania, Italy 25 - 30 June 2023

# VIII MEDITERRANEAN SCHOOL OF COMPLEX NETWORKS

MSCx networks

# VIII MEDITERRANEAN SCHOOL OF COMPLEX NETWORKS

In the last decade, network theory has been revealed to be a perfect instrument to model the structure of complex systems and the dynamical process they are involved into. The wide variety of applications to social sciences, technological networks, biology, transportation and economic, to cite just only some of them, showed that network theory is suitable to provide new insights into many problems.

Given the success of the seventh Edition in 2022 of the Mediterranean School of Complex Networks, we call for applications to the eighth Edition in 2023.

**SCHOOL DIRECTORS:**

Alex Arenas (URV)
Vincenza Carchiolo (UNICT)
Manlio De Domenico (UNIPD)
Mattia Frasca (UNICT)
Giuseppe Mangioni (UNICT)

**ORGANIZERS:**

Giuseppe Mangioni (UNICT)
Alex Arenas (URV)

**LOCAL ORGANIZERS:**

Serafina Agnello
Georgia Fichera
Marco Grassia (UNICT)

# PRIZES AND FELLOWSHIPS

The School will award two prizes:

- to one attendant, for the participant talk,
- to one lecturer, for the best lecture.

PhD students and Junior Post Doctoral researchers (no more than two years from their PhD completion) who are members of the CSS (cssociety.org/home) are eligible to get a fellowship covering the School fee.

COMPLEX SYSTEMS SOCIETY

# LECTURERS

## KIMBERLY GLASS

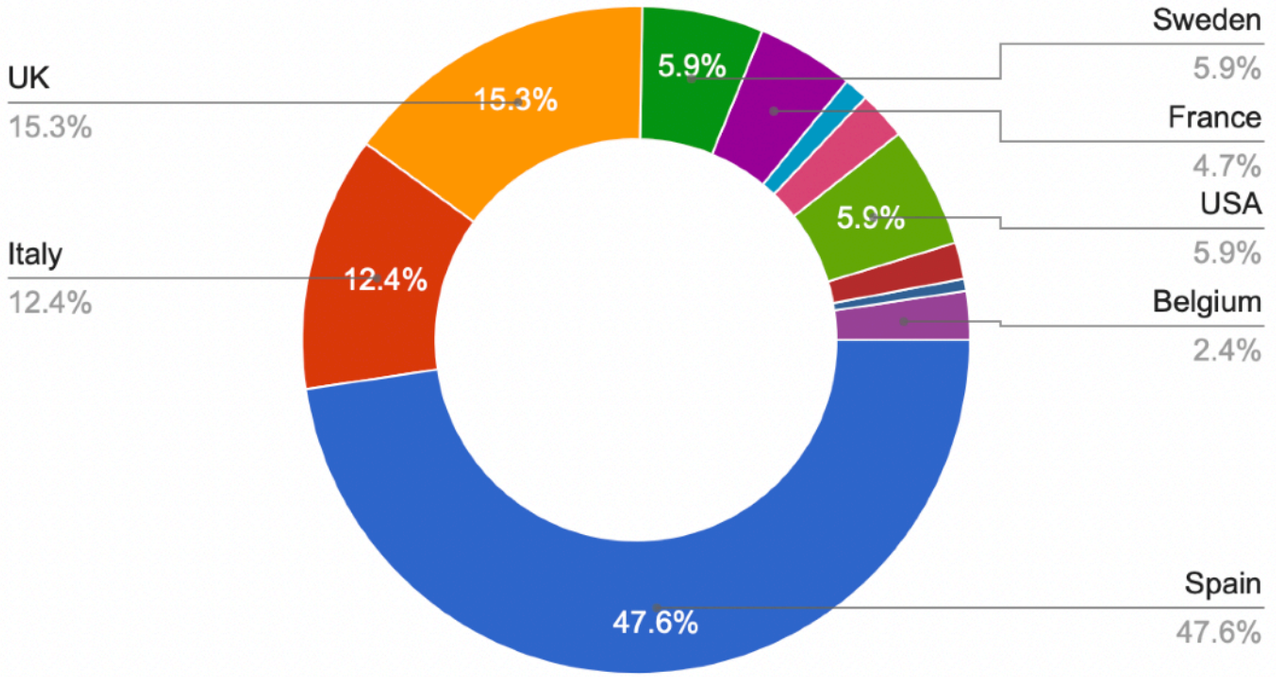
(Harvard University, USA)

## SERGIO GÓMEZ

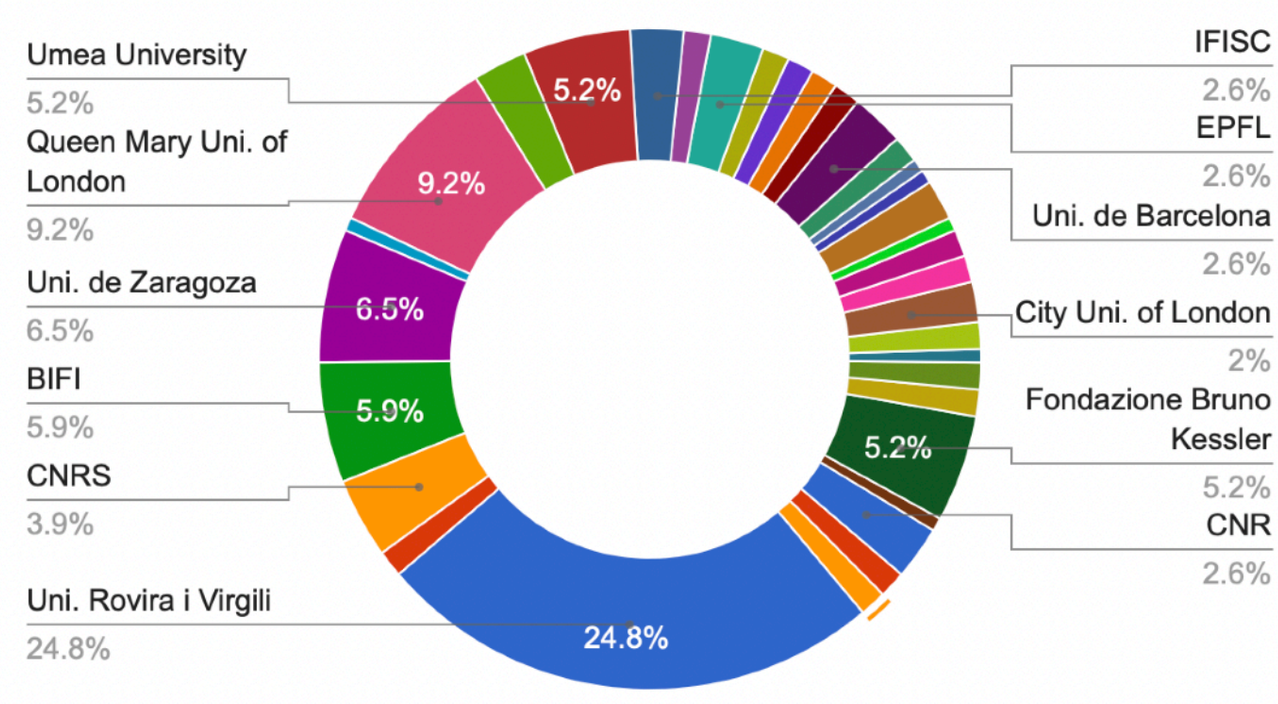
(Universitat Rovira i Virgili, Spain)

## SAMIR SUWEIS

(University of Padua, Italy)




Lecturers by country of all editions




Lecturers by institutions of all editions

# SPEAKERS

## MARC BARTHELEMY
(Institut de Physique Theorique in Saclay, France)

## CLARA GRANELL
(Universitat Rovira i Virgili, Spain)

## VITO LATORA
(University of Catania and QMUL, Italy and UK)

## JORDI NIN
(ESADE, Spain)

# SCHOOL DIRECTORS

## ALEX ARENAS
(Universitat Rovira i Virgili, Spain)

## VINCENZA CARCHIOLO
(Università degli studi di Catania, Italy)

## MANLIO DE DOMENICO
(Università degli studi di Padova, Italy)

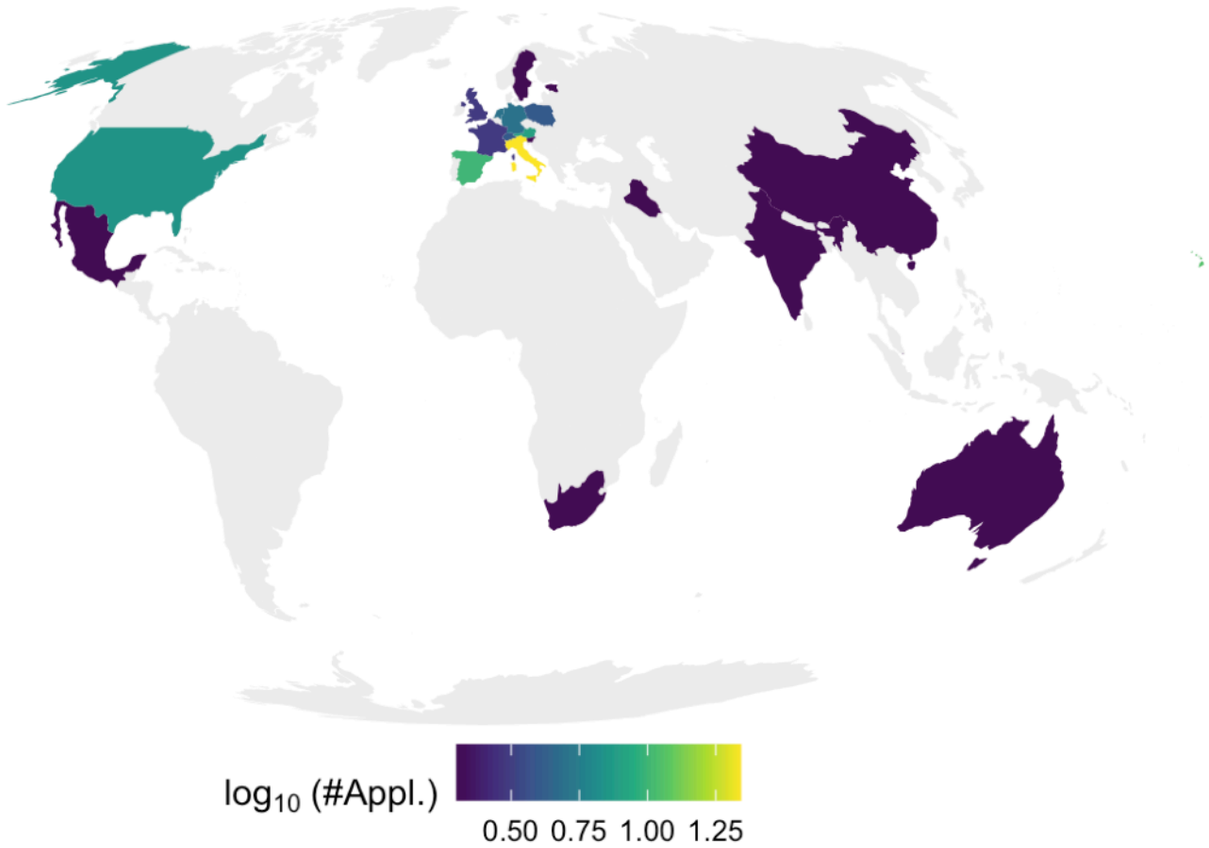
## MATTIA FRASCA
(Università degli studi di Catania, Italy)

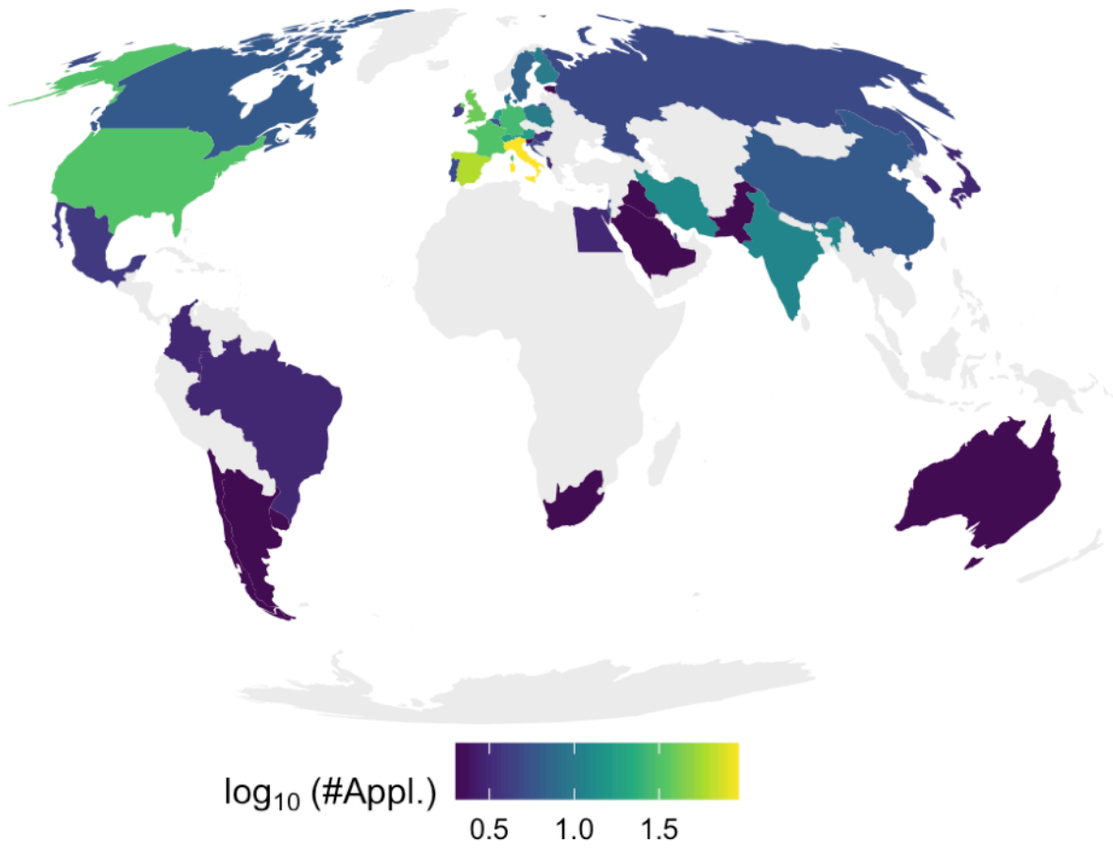
## GIUSEPPE MANGIONI
(Università degli studi di Catania, Italy)

# STUDENTS

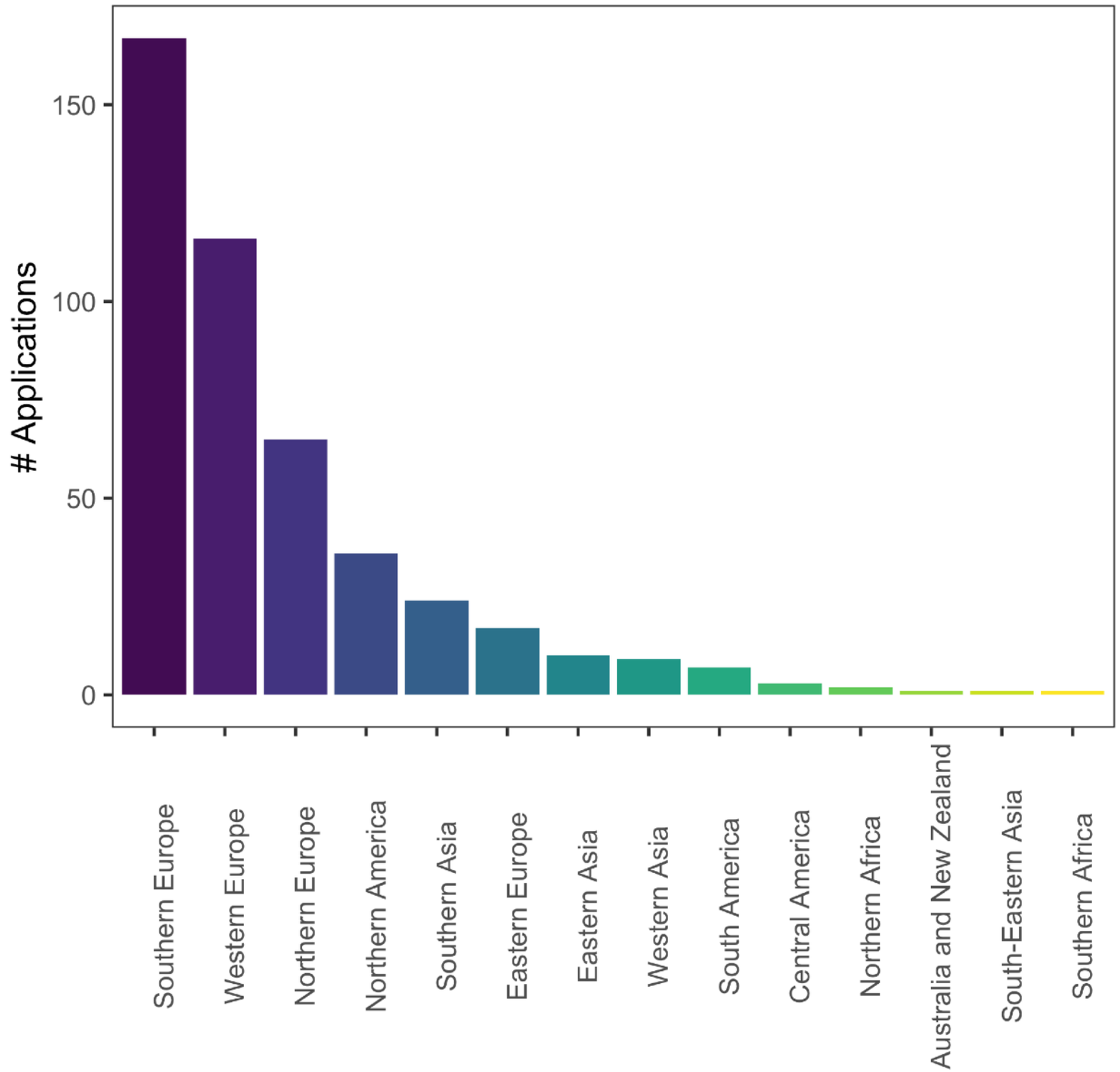
| Name | Affiliation |
|---|---|
| Alessandra Corso | University of Catania |
| Alice Doimo | University of Padova |
| Bernat Salbanyà | ESADE - Universitat Ramon Llull |
| Bremaud Louis | Paris-Saclay University |
| Celine Sin | Max Perutz Labs |
| Chiara Condorelli | University of Catania |
| Christos Charalambous | IFISC (CSIC-UIB) |
| Cinzia Tomaselli | University of Catania |
| Clelia Corridori | University of Padova |
| Davide Zanchetta | University of Padova |
| Dhrubajyoti Biswas | Indian Institute of Technology Madras |
| Diego Perazzolo | University of Padova |
| Fabio Menegazzo | University of Padova |
| Gabriele Puglisi | University of Catania |
| Giacomo Baruzzo | University of Padova |
| Giacomo Barzon | University of Padova |
| Giovanni Palermo | Università Sapienza |
| Giulia Cesaro | University of Padova |
| Hana Krakovska | Medical University of Vienna |
| Hugo Pérez-Martínez | University of Zaragoza |
| Inês Sampaio | Politecnico di Milano |
| Jill de Ron | University of Amsterdam |
| Karoline Huth | University of Amsterdam |
| Kimberly Nestor | Carnegie Mellon University |

| Name | Affiliation |
|---|---|
| Lorenzo  Buffa | University of Roma Tor Vergata |
| Lorenzo Di Meco | University of Bologna |
| Maarten van den Ende | University of Amsterdam |
| Maier Markus | Munich School of Philosophy |
| Marya Poterek | University of Notre Dame |
| Massimo Gollo | University of Catania |
| Meher Chaitanya Pindiprolu | ETH Zurich |
| Santiago Lamata Otín | University of Zaragoza |
| Sara Venturini | University of Padova |
| Swanand Khanapurkar | Arizona State University |
| Pablo Valgañón | University of Zaragoza |
| Pau Esteve | IFISC |
| Ria Hoekstra | University of Amsterdam |
| Sara Benedetti | The University of Adelaide |
| Sara M. Vallejo-Bernal | PIK |
| Simon David Lindner | Medical University of Vienna |
| Tamanna Urmi | Northeastern University |
| Teresa Lázaro | Universitat Rovira i Virgili |
| Tina Šfiligoj | University of Ljubljana |
| Zhang Zhang | Beijing Normal University |
| Wassmer Jonas | University of Potsdam |
| Wei Zhang | ETH Zurich |
| Yueting Han | University of Warwick |




Maps colored by the number of applications to the VIII edition (left) and across all MSCX editions (right)




Distribution of the number of applications by world region, across all MSCX editions.

# PROGRAM

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 26 June | 9:00 | 10:00 | 10:30 | 12:00 | 15:30 | 17:00 | 17:30 | 18:30 | |
| | **OPENING** Giuseppe Mangioni Alex Arenas | **BREAK** | **SESSION I PART I** Sergio Gómez | / | **SESSION I PART II** Sergio Gómez | **BREAK** | **STUDENT TALKS I** | / | |
| 27 June | 9:00 | 10:30 | 11:00 | 12:30 | 16:00 | 17:00 | 17:30 | 18:30 | |
| | **SEMINARS I** Jordi Nin | **BREAK** | **STUDENT TALKS II** | / | **SESSION II PART I** Kimberly Glass | **BREAK** | **SESSION II PART II** Kimberly Glass | / | |
| 28 June | 9:00 | 10:30 | 11:00 | 12:30 | 16:00 | 17:00 | 17:30 | 18:30 | 20:00 |
| | **SESSION III PART I** Samir Suweis | **BREAK** | **SESSION III PART II** Samir Suweis | / | **STUDENT TALKS III** | **BREAK** | **STUDENT TALKS IV** | / | **SOCIAL DINNER** |
| 29 June | 9:00 | 10:30 | 11:00 | 12:30 | 15:00 | | | | |
| | **SEMINARS II** Marc Barthelemy | **BREAK** | **PROJECTS TIME** | / | **ETNA TOUR** | | | | |
| 30 June | 9:00 | 10:30 | 11:00 | 12:30 | 16:00 | 17:00 | 17:30 | 18:30 | |
| | **SEMINARS III** Clara Granell | **BREAK** | **SEMINARS IV** Vito Latora | / | **PROJECTS TIME** | **BREAK** | **CLOSING CERIMONIES** | / | |

# SESSION

SESSION I

## STRUCTURE OF COMPLEX NETWORKS

Sergio Gómez

The omnipresence of complex networks in all kinds of disciplines, and the fact that some of their structural properties are shared by many of them, has led to an increasing interest in the study of complex network. Nowadays, network science has become an essential toolkit to analyze, model and understand any system exhibiting pairwise interactions between its components. We will explain the main structural characteristics of complex networks, the mathematical and computational tools for their analysis, and some models that help to explain the appearance of some of these characteristics.

I

## STRUCTURE OF MULTILAYER NETWORKS

Sergio Gómez

Multilayer networks are networks in which the edges can be of different types, thus forming layers. We will review the main structural features of these networks, highlighting the differences with respect to standard single-layer networks. Although it may seem that multilayer networks are particular cases of complex networks, we will show that the multilayer structure can be intrinsically different, inducing unexpected emergent behaviors that could not be predicted beforehand.

II

SESSION II

## NETWORK MEDICINE: CONCEPTS, METHODS, AND APPLICATIONS

Kimberly Glass

Network Medicine applies techniques from network science to investigate disease. A range of network medicine approaches have been developed to improve the diagnosis, prognosis, and treatment of complex diseases. Modeling molecular networks by integrating multiple types of Omics data, in particular, provides a powerful way to identify disease-related biological mechanisms and dissect disease heterogeneity. Along these lines, our group has developed a suite of computational approaches that support: (1) effectively integrating multi-Omic data to model gene regulatory networks; (2) performing network analysis to identify regulatory mechanisms mediating changes in disease state; and (3) linking network alterations with patient phenotypes to support precision medicine. In this lecture series, I will provide a broad introduction to the field of Network Medicine as well as a summary of how molecular networks have been applied in biology and medicine. I will also give a detailed review of a collection of methods our group has developed for gene regulatory network reconstruction and analysis. Finally, I will discuss several specific applications in which we have used these approaches to discover new features of disease and to understand the complex regulatory processes at work across patients.

SESSION III

## ECOLOGICAL NETWORKS, DYNAMICS AND ECOSYSTEM STABILITY

Samir Suweis

In these two lectures, I will present some classical models of ecosystems dynamics, ranging from mean field and stochastic models to multi-dimensional deterministic ones. I will show how the structure of ecological networks is fundamentally intertwined to their population dynamics. I will finally illustrate how both structure and dynamics determines the stability of ecosystems.

# SEMINARS

SEMINARS I

## MODELLING FINANCIAL DISTRESS PROPAGATION

Jordi Nin

Financial networks have been the object of intense quantitative analysis during the last decades. Their structure and the dynamical processes on top of them, are of utmost importance to understand the emergent collective behavior behind economic and financial crises. Daily business interactions form a direct and weighted customer-supplier network whose structure has in-depth implications for its functioning. A company's financial distress depends on the capacity of its clients to fulfill their payments. Otherwise, a firm cannot keep working unless it applies for a loan. Recent financial crises have prompted much new research on the interconnectedness of companies and the extent to which it contributes to systemic fragility. In this talk, we study the interplay between network complexity and market stability in a deliberately simplified model for financial distress propagation. To this aim, we introduce a stylized model to understand the domino effect of distress in client-supplier networks, providing a theoretical analysis, and applying it to several synthetic networks and a real customer-supplier network supplied by one of the largest banks in Europe. Besides, the model allows researchers to investigate possible scenarios for the functioning of the financial distress propagation and to assess the complete network's economic health. The described model is based on the combination of two stochastic terms: a) an additive noise, accounting for the capability of trading and paying obligations, and b) a multiplicative noise representing market variations. Both parameters are crucial to determining the maximum default probability and the diffusion process characteristics.

SEMINARS II

## SPATIAL GROWTH OF URBAN TRANSPORTATION INFRASTRUCTURES

Marc Barthelemy

Roads and subways are crucial networks that constitute in some sort the backbone of a city. These networks evolve in time and space and usually co-evolve with cities, so that their understanding is critical for constructing a science of cities. In this lecture, after a general introduction about urban networks, I will discuss the evolution of street networks and subways in large cities. I will introduce the main tools for measuring their salient properties, discuss the main features of their growth and discuss some models for these systems, as well as some challenges for future research.

SEMINARS III

## COMMUNITY DETECTION

Clara Granell

Community detection is an important problem that consists on grasping the intrinsic topological structures of networked data, without any previous knowledge about the size or number of groups to be found. This is of utmost importance in exploratory data analysis, specially in experimental fields like biology, chemistry, and many others. The main difficulty that scientists face when trying to do community analysis relies on finding the appropriate definitions and algorithms for each problem at hand. Nowadays, a myriad of methods are available, and some are even embedded in network analysis tools, making it easy for scientists to apply the most popular community algorithm right away, but also hiding the whole community detection process in a black box. In this lecture we will review community detection from its very definition, considering the advantages and drawbacks of the most popular approaches, in hopes to build a grounded knowledge about this problem so that every scientist is able to critically choose the appropriate solution for his problem.

SEMINARS IV

## THE DYNAMICS OF SOCIAL SYSTEMS WITH HIGHER-ORDER INTERACTIONS

Vito Latora

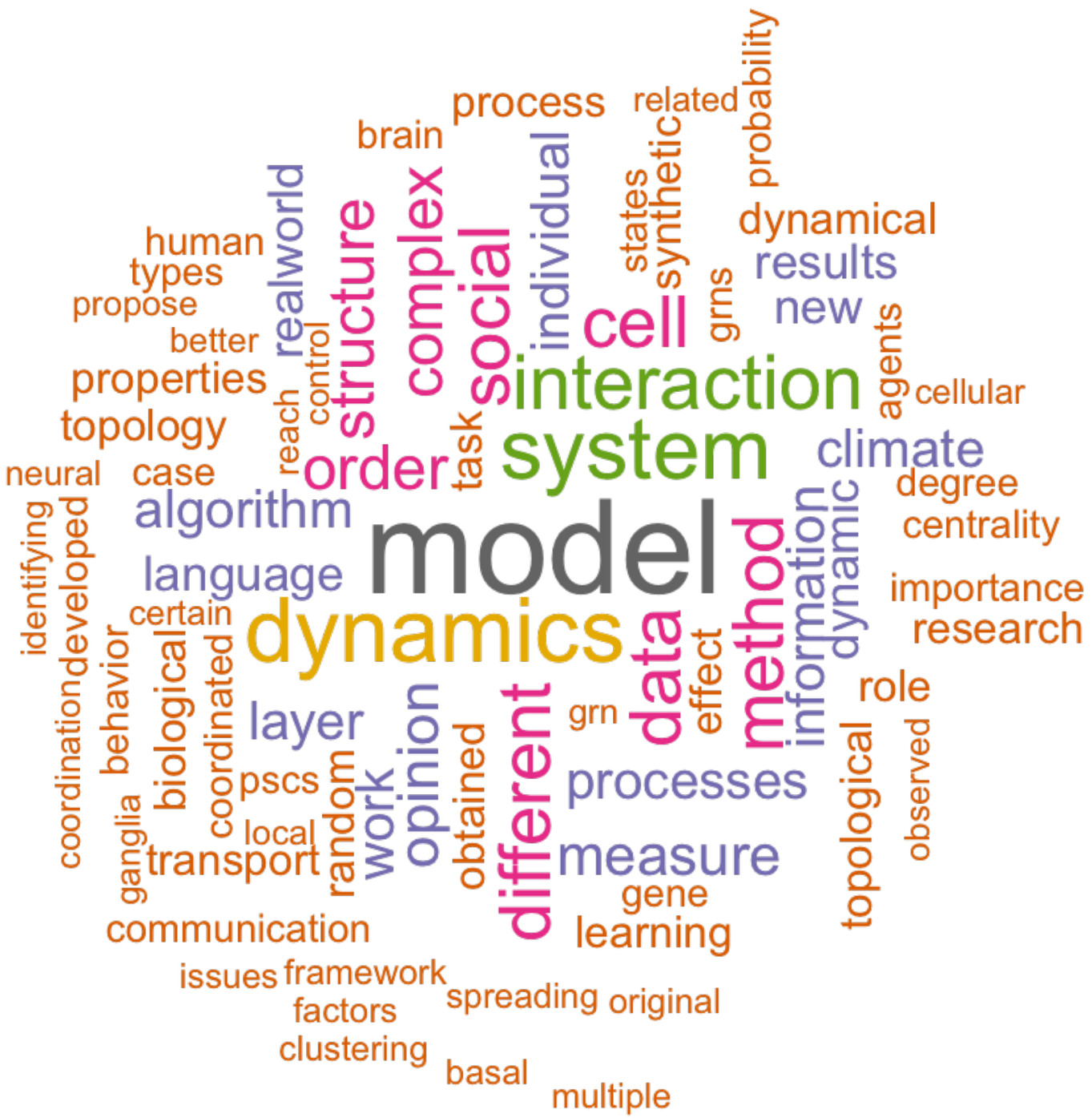
Networks are made of nodes and links. Hence, they are suited to study processes, such as the spreading of a disease in a population, in which transmission occurs through pairwise contacts. Conversely, networks cannot describe well other dynamical processes, such as the adoption of innovation or the formation of opinions in a social system, where more complex mechanisms of transmission and reinforcement are at work. In this lecture, I will discuss how to go beyond complex networks **[1]** and I will illustrate, with three different examples, how to use higher-order networks to better model social dynamics.

I will first present a higher-order model of social contagion in which a social system is represented by a simplicial complex, and the contagion can occur through interactions in groups of different sizes **[2]**. I will show that higher-order interactions induce the emergence of a discontinuous phase transition in the model, with a related bistable region where healthy and endemic states co-exist. This result can help explaining why critical masses are required to initiate social changes.

I will then introduce a general framework to study collective behaviors in networks of dynamical units coupled through two-body and three-body interactions. I will show how to derive general conditions for the existence and stability of synchronization, in the form of a Master Stability Function, and I will illustrate with some case studies how higher-order interactions can help stabilizing otherwise unstable synchronized states **[3]**.

Finally, I will discuss a method to extend evolutionary games to higher-order networks **[4,5]**. Considering a system of many players involved both in pairwise and in three-player Prisoner Dilemmas, described by the hyperedges of a hypergraphs with tunable structure, I will show that, when the fraction of three-player games is larger than a certain threshold, the dynamics shows an explosive transition to a bistable state where, besides full defection, a cooperative stable state emerges.

**[1]** https://doi.org/10.1016/j.physrep.2020.05.004 **[2]** https://www.nature.com/articles/s41467-019-10431-6 **[3]** https://www.nature.com/articles/s41467-021-21486-9 [4] https://www.nature.com/articles/s41562-020-01024-1. **[5]** https://arxiv.org/abs/2303.11475




Word cloud of the terms most frequently appearing in the accepted abstracts. Size is proportional to term frequency.

# STUDENT TALKS I

## NETWORK MEDICINE

**26 JUNE**

I

**Full**

### GENE REGULATORY NETWORK REMODELING THROUGH EMBRYONIC DEVELOPMENT TRAJECTORIES

Celine Sin

During embryo development, gene regulatory networks (GRNs) orchestrate dynamically changing gene expression programs (GEPs) to enable coordinated cell differentiation juxtaposed with stable maintenance of diverse cell types. While key transcription factors are known to promote certain differentiation events, it is not clear how GRNs achieve the dynamic range of GEPs. Network theory has demonstrated numerous relationships between network structure and dynamic processes arising from them, but these principles have not been studied in GRNs. We harmonized 21 scRNA-seq human embryo datasets to build a series of GRNs resolved to cell types and developmental time. With the harmonized data, we trace pseudotime trajectories and reconstruct the transcriptomic manifold evaluating for GEP stability, attraction points, and bifurcation points. These local manifold properties are tied to the dynamic processes controlling cell fates, and by linking them to topological structure of the underlying GRNs, we will better understand GRN remodeling and how this contributes to the enormous dynamic range of GEPs.

II

**Full**

### OPPOSING ENGAGEMENT OF CEREBELLAR AND BASAL GANGLIA NETWORKS WITH SHIFTS OF CORTICAL NETWORK TOPOLOGY

Kimberly Nestor

The brain is a dynamical network, shifting from integrated to segregated states depending on task demands (Shine & Poldrack, 2018). An integrated network facilitates information flow across communities, while segregated isolates information flow to within communities. The basal ganglia and cerebellum are hypothesized to be driving forces in shifting the cortex from integrated to segregated states respectively, allowing for flexibility in task completion (Shine, 2021). To test this hypothesis we used fMRI in humans and the modularity index to determine change of cortical networks across task performance. Eigenvector centrality was used to determine engagement of subcortical regions basal ganglia and cerebellum temporally. Cortical topology was highly flexible, with decreased modularity during more complex task blocks. Subcortical regions showed engagement at varying portions of the tasks; basal ganglia increased earlier, while cerebellar increased at the end of task blocks. Basal ganglia engagement preceded shifts in cortical modularity, consistent with a control effect.

III

Full

## INFERRING GENE REGULATORY NETWORKS IN PLURIPOTENT STEM CELLS

Clelia Corridori

Pluripotent stem cells (PSCs) are a fundamental tool for regenerative medicine since they can give rise to all differentiated cell types and can be expanded indefinitely in vitro. The PSCs differentiation process is governed by transcription factors organised in a Gene Regulatory Network (GRN). We developed an unsupervised computational model capable of inferring the GRN of differentiating murine PSCs. Starting from gene expression data, we inferred the GRN interactions as couplings of an Asymmetric Kinetic Ising model. Moreover, our method can predict the PSCs behaviour in response to single and triple gene knockouts, properly resembling the experimental data. We compared it to the state-of-the-art model, SCODE, showing that our model outperformed it in inferring known interactions and generating new data. Overall, the findings suggest that our model could provide new insights into the description of the PSCs differentiation process.

IV

Full

## A STATISTICAL AND NETWORK-BASED METHOD TO INFER CELLULAR COMMUNICATION FROM SINGLE-CELL RNA SEQUENCING DATA

Giulia Cesaro

The advent of single-cell RNA sequencing (scRNA-seq) technologies offers unprecedented opportunities to study transcriptional profiles of individual cells, thus investigating heterogeneity and cellular composition within a biological sample/tissue. The interaction between cells plays a crucial role in controlling and coordinating biological processes (e.g. from organ development to cellular activities) while alterations in the communication mechanism may be associated with an experimental condition. Cellular communication involves the interactions of different molecules both across cells, e.g. intercellular signaling mediated by ligand-receptor binding, and inside each cell, e.g. intracellular signaling triggering transcriptional and metabolic responses. In my talk, I will present a bioinformatics method to infer and quantify cellular communication at both intercellular and intracellular signaling level from scRNA-seq data. To handle the complex and multidimensional nature of data, the proposed tool exploits statistical methodology to quantify interactions across cells, as well as network-based methods to study and represent biological intra-signaling pathway.

V

## BIOINFORMATICS FOR COMPLEX BIOLOGICAL SYSTEMS: UNRAVELING CELL-CELL AND BACTERIAL INTERACTIONS

**Full**

Giacomo Baruzzo

In mammals, tissues and organs can be seen as systems of multiple entities (cells) that are spatially and temporally organized, can interact with each other, and perform dynamic biological processes (e.g. react to a disease). A better knowledge of such processes is the key element for breakthrough advancements in molecular biology and medicine. In terms of bacteria, microbiota composition studies are of extreme interest, since it has been widely shown that resident microorganisms shape the ecological niche they inhabit, mainly through the different types of interaction between species. Considering the ubiquity of bacteria in the environment, their role in persevering the biodiversity, and the threats to human and animal health, a better understanding of bacteria community interactions is of pivotal importance for many fields. In this presentation, I will describe my research activities in developing algorithms, methods and software for the analysis of omics data from such complex biological systems.

VI

## PREDICTION METHODS FOR ANTIMICROBIAL RESISTANCE

**Flash**

Chiara Condorelli

Antimicrobial Resistance (AMR) is one of the most serious global health issues. In this work, I analyze different approaches to predict AMR. Particularly, I am studying two open research projects on this subject: the problem of identifying compartmental model parameters to predict the trend of the population resistant to a specific bacterium, and the prediction of bacterial resistance from genomics data, using machine learning techniques. In my talk, I will explain the basic ideas I developed during the first five months of my PhD program to deal with these topics.

VII

## GRAPH ALIGNMENT PROBLEMS IN C-ELEGANT CONNECTOMES

**Flash**

Teresa Lázaro Sánchez

The graph alignment problem refers to the task of finding the correspondence mapping between two or more equivalent graphs. In particular, we align four experimental connectomes obtained from the brains of C.elegans. Since same specie individuals share common brain features, it is meaningful to search for the mappings between their connectomes: We can consider their brains as variations of a common ""brain template"", also called the blueprint. Therefore, our aim is to infere, through Bayesian probability ,the right permutations between the node labels of the four brain graphs, as well as identifying the most likely blueprint that generates these connectomes. To maximize their Bayesian probability (the best solution), we developed a Parallel Monte Carlo algorithm that incorporates biological assumptions about the nodes, such as the knowledge of the neuroblast group to which each neuron belongs or the a priori knowledge of certain node labels (called the anchors).

# STUDENT TALKS II

## NETWORK DYNAMICS

**27 JUNE**

I

### UNRAVELING THE MESOSCALE ORGANIZATION INDUCED BY NETWORK-DRIVEN PROCESSES

**Full**

Giacomo Barzon

Complex systems are characterized by emergent patterns created by the non-trivial interplay between dynamical processes and their networks of interactions. Topological or dynamical descriptors alone are not enough to fully embrace this interplay, and many times one has to resort to dynamics-specific approaches. To fill this gap, we introduce a metric -- named Jacobian distance -- inherently related to the spatiotemporal spreading of a perturbation, allowing to exploit the latent geometry underlying network-driven processes. We show that this geometry is sensitive to both the specific features of the dynamics and the topological properties of the network. We analyze how the effective mesoscale organization of a network is affected, showing how the spectrum of the Jacobian matrix determines under which conditions functional modules are not trivially mapped to topological ones. Finally, we show that our framework outperforms network communication models in explaining functional communities from structural data of human brain networks.

II

**Full**

### VOTER MODEL WITH LATENCY TIME

Giovanni Palermo

Variation of the voter model on complex networks with the inclusion of a latency time after changing opinion reveals totally new and richer dynamics, leading to opinion waves and shifts in global consensus on binary opinions.

III

### A NEW MEAN FIELD APPROXIMATION FOR EPIDEMICS DYNAMICS ON HETEROGENEOUS NETWORKS

**Full**

Louis Bremaud

As we have seen with the recent pandemic crisis, the heterogeneous structure of our social contacts plays a crucial role in epidemics dynamics at the start of its spread, but also during its growth, with the presence of “super-spreaders”. However, if the usual mean-field approximation is sufficient to model the beginning of epidemics, it fails to reproduce simulated epidemics at large scale which are obtained through a usual Markov process on networks. In our work, we introduce a new mean-field approximation, more refined, which allow to correctly reproduce the numerical results and get a better understanding about how the epidemic propagate inside the network by describing the time evolution of correlations. This work should allow us to implement a mean field game approach on such networks.

IV

## MULTICONSENSUS INDUCED BY NETWORK SYMMETRIES AND ITS ROBOTIC IMPLEMENTATION

Full

Cinzia Tomaselli

In multi-agent systems, the multiconsensus is a dynamic behavior where the agents are grouped into clusters and the agents of each group reach the consensus. In this work, we provide a control protocol that exploits the features of symmetric networks to achieve multiconsensus in systems of agents with single integrator dynamics. In particular, this protocol drives the system to reach a state that is parallel to the leading eigenvector of the adjacency matrix describing the interaction graph. In order to put this protocol into practice, we use a team of six Elisa3 robots to solve the rendezvous problem: each robot can rely on the information about the location of its neighbors to reach an agreement on the point where to meet with the other units of the same cluster.

V

## CONFORMITY VERSUS CREDIBILITY: A RUMOR-BELIEF COEVOLUTION MODEL

Full

Wei Zhang

The opinion people hold about a piece of information and its spreading are interconnected, influencing one another, as people may choose to spread rumors they believe in and discard those they do not. Meanwhile, an individual's opinion may be influenced by their peers' opinions and observed behaviors. We present a coevolution model of opinion dynamics and rumor spreading in social systems. We define our coevolutionary model in a two-layer social network, where an influence layer captures the evolution of opinion by games, and a communication layer captures how information spreads among individuals. Using analytical and numerical tools we demonstrate consistent behavior of the model by identifying a critical spreading rate for rumor outbreaks.

VI

## LANGUAGE COMPETITION ON COEVOLUTIONARY NETWORKS: COUPLED NODE AND LINK DYNAMICS

Full

Christos Charalambous

Motivated by an observed disappearance of minoritarian languages in the recent years, a great deal of attention has been given in the modelling of language competition in order to understand the factors that promote this disappearance and the dynamics that lead up to it. With this in mind, we build on an existing model of language competition, where a coupled evolution of node (language preference) and link (language use) states was studied. We extend the model to allow for the case where agents have the freedom to adapt their local interaction topology in accordance to their language preference. We find that permitting this can result in a polarized network. What is more, we study numerically the effect of the network size on the probability to reach consensus on the language usage, as well as on the relative size between the minority and majority language groups in the case of polarization.

VII

## A NEW MEASURE OF COORDINATION IN ONLINE SOCIAL MEDIA: NETWORK ANALYSIS OF INFORMATION SPREAD DURING THE RUSSIAN INVASION OF UKRAINE.

Full

Sara Benedetti

Online social platforms are targeted by centrally coordinated disinformation campaigns. Even though a large spectrum of coordination can be observed in social media, usually literature focuses exclusively on highly coordinated activity. Coordination networks are often built by linking accounts sharing a minimum number of times the same (or similar) content within a small timeframe. However, these multiple thresholds implicitly assume a scale in the system and ignore the full range of coordination in social media. We propose a new measure of coordination between pairs of accounts that allows instead this characterisation and we show that it can be used to identify centrally coordinated campaigns without the need of multiple filtering procedures. We test our approach by studying the spread on Twitter of messages supporting Ukraine or Russia at the beginning of the 2022 Russian invasion of Ukraine: the results indicate the presence of a pro-Russia centrally coordinated information campaign.

VIII

## EMERGENCE OF OPINION POLARIZATION IN WEIGHTED CONTACT STRUCTURES

Full

Hugo Pérez-Martínez

The emergence of political polarization is usually linked to the advent of social networks, which can generate echo chambers that isolate people from opposing perspectives. However, real-world relationships are not solely dependent on one's opinion about certain issues, but also on friendship, kinship, professional ties and the like, usually featuring cross-cutting interactions whose effect on one's opinion lies on the importance assigned to the other's point of view. To consider this, we develop an opinion model aplicable to static, weighted graphs. In our model, agents always interact with the same set of neighbors, being influenced by their opinions and giving more importance to like-minded individuals by means of the weights. We find that polarization is indeed possible under this formalism, and that the polarized configurations generated mimic those obtained in real-world surveys about polarized issues, which allows us to classify multiple issues based on the inferred optimal parameters.

IX

Flash

## ALCOHOL USE AS A SOCIAL-CONTAGIOUS PROCESS

Maarten van den Ende

Alcohol use has been found be a socially influenced phenomena where the drinking behaviour of an individuals social network plays an important role in their own behaviour. I use the longitudinal social network data of the Framingham Heart study to investigate to what extent alcohol use is affected by the structure of the social network, and to calibrate a three-state epidemiological model.

X

Flash

## MODELING DENGUE VIRUS TRANSMISSION AND BEHAVIORAL CONTROL IN A COUPLED CONTAGION SYSTEM

Marya Poterek

Though control strategies for dengue virus can vary significantly in efficacy and scale of implementation, human behavior is an important component of their success. Behavior can influence compliance patterns  with spraying campaigns and participation in mosquito habitat reduction, namely the elimination of standing water. The nature of the relationship between that influence and the outcomes we observe in behavioral studies is difficult to pinpoint, though, since several factors influence the presence of standing water in a home besides behavioral control alone. To explore the possible consequences that this relationship may have on the efficacy of behavioral interventions, we developed a mechanistic model for human behavior, implemented within an existing agent-based model for dengue transmission. Here, we present preliminary results from this model framework and explore the role assumptions about community network structures might play in the success of behavior-focused interventions.

# STUDENT TALKS III

## APPLICATIONS

**28 JUNE**

I

**Full**

### SUSTAINABILITY OF COMMON POOL RESOURCES

Fabio Menegazzo

Common pool resources are goods that are available to all members of a community and whose usage by one agent degrades their quality or reduces their availability for others. It is of paramount importance, for this kind of resources, to understand under which conditions they are sustainable instead of getting exhausted. Our results show that these opposing outcomes are strongly dependent on the topology of the network establishing the links between the consumers, particularly on its connectance; moreover, we notice an echo-chamber effect, with groups of people with the same attitude towards the resources forming close groups and developing negative relations with those who think differently. All this was obtained with Erdos-Renyi graphs: we'd like to extend it to more real-world-like graphs, such as scale-free, small-world or even real world economic and social networks.

II

**Full**

### USING COMPLEX NETWORKS TO UNTANGLE THE CLIMATE SYSTEM

Sara M. Vallejo-Bernal

To unravel the dynamics of the climate system over different spatial and temporal scales, we analyse climate records using complex networks. Unlike most real-world networks where nodes and edges are well defined, climate networks are functional: nodes are identified with geographical locations, and edges are placed between nodes if the corresponding climate records share some statistical similarity, regardless of whether they are physically connected or not. This approach is based on the hypothesis that the internal structure of the climate network encodes the interactions between the different components of the climate system, which can then be revealed by appropriate complex network measurements. The aim of this talk is to give a short introduction on how to construct a climate network, revisit the most relevant contributions of the last decades and present the overarching challenges we are currently facing on this young and emerging field.

III

Flash

## PARALLEL COMPUTING APPROACH IN NEURAL NETWORKS LEARNING

Gabriele Puglisi

Neural networks based on back-propagation learning algorithm and gradient descent algorithm are the first and the easiest tools developed for machine learning. But as highlighted in the past, these traditional neural networks suffer from their slow convergence rate. In the first months of my PhD activities, a new algorithm is implemented in order to improve the speed of the learning phase, by exploiting the power of the parallel computing to perform a suitable number of additional neural networks which work concurrently to the principal network.

IV

Flash

## QUANTIFYING HISTORY IN EVOLUTION

Swanand Khanapurkar

The evolutionary dynamics in the genotype space is a Markovian dynamics viz. a Poisson process induced by mutations. The genotype network can’t retain the memory of any dynamical processes happening on it. However, it seems that the same dynamics becomes non-markovian and history-dependent in the phenotype space. This might be due to the non-trivial structure of genotype-phenotype maps. We attempt to quantify this by analyzing the non-markovinity of the phenotypic trajectories. We test the hypothesis that a random walk on a genotype network gets directly mapped onto a self-modulated process, far from a random walk, on the phenotype network.

V

Full

## LEARNING THE RIGHT LAYERS: A DATA-DRIVEN LAYER-AGGREGATION STRATEGY FOR SEMI-SUPERVISED LEARNING ON MULTILAYER GRAPH

Sara Venturini

Clustering (or community detection) on multilayer graphs poses several additional complications with respect to standard graphs as different layers may be characterized by different structures and types of information. One of the major challenges is to establish the extent to which each layer contributes to the cluster assignment in order to effectively take advantage of the multilayer structure and improve upon the classification obtained using the individual layers or their union. However, making an informed a-priori assessment about the clustering information content of the layers can be very complicated. In this work, we assume a semi-supervised learning setting, where the class of a small percentage of nodes is initially provided, and we propose a parameter-free Laplacian-regularized model that learns an optimal nonlinear combination of the different layers from the available input labels. The learning algorithm is based on a Frank-Wolfe optimization scheme with inexact gradient, combined with a modified Label Propagation iteration. We provide a detailed convergence analysis of the algorithm and extensive experiments on synthetic and real-world datasets, showing that the proposed method compares favourably with a variety of baselines and outperforms each individual layer when used in isolation.

VI

Full

## NETWORK RENORMALIZATION BY GRAPH NEURAL NETWORK

Zhang Zhang

The renormalization of the network refers to finding a miniaturized version of the network whose properties are as similar as possible to the original network. Classical methods are often based on certain renormalization rules set by researchers. In this work we try to use a graph neural network to renormalize the network, we use the similarity of the partition function as the loss function, resulting in a small network similar to the original network both in structure and diffusion dynamics. Compared with other methods, our method is faster, more flexible, and can be applied to larger networks.

VII

## HIGHER-ORDER STRUCTURES ROLE: ENFORCERS OR DRIVERS

Full

Santiago Lamata Otín

The aim of this talk is to show how the arrangement of higher order structures is of paramount importance for the emergent phenomenology. They can either enforce the pairwise dynamics or yield towards new ones. After motivating the difference with real data sets examples, we propose a novel metric to interpolate between the two scenarios: the overlapness. Besides, we create a synthetic structure with maximizes the measure, and allows us to go through all the scenarios. In order to show the effect on the dynamics we consider two well known situations: higher order contagion and synchronization. In both cases, the inclusion of higher order interactions results in a change on the transition order, which becomes explosive. We here show how, for higher overlapness values, the explosive nature is suppressed, recovering the original pairwise-driven dynamic. The fact that results are found in both dynamics shows universality in our results.

# STUDENT TALKS IV

## TRANSPORTATION/URBAN NETWORKS

**28 JUNE**

I

**Full**

### AIR TRANSPORT FROM A COMPLEX NETWORK PERSPECTIVE: INSIGHTS INTO MOBILITY AND DELAY PROPAGATION

Pau Esteve

The presentation will focus on my PhD thesis, which aims to study air transport as a complex system using complex networks as the primary tool. First, I will discuss different network representations useful to analyze this socio-technical system; ranging from the well-known airport network to the network comprised of airways. I will highlight how networks can help in studying the mobility of flights and identifying inefficiencies or vulnerabilities within the system. Second, I'll present the problem of delays in air transport, which have huge economic and social implications. Airports can receive inbound delayed flights from their neighbors, and propagate them in a potentially nonlinear way, producing reactionary delays. I will explore how networks can aid in our understanding of this propagation phenomenon, such as through functional networks, where links are associated with causal delays.

II

**Full**

### DYNAMICAL AND STATISTICAL PROPERTIES OF SIMPLE TRANSPORT MODELS

Lorenzo Di Meco

A schematic representation of a transport network is built by using dynamical systems on graphs. We apply a Markov model to the average dynamics of two different situations: when only one particle per unit time moves and when all non-empty nodes can move a particle. In the first case we compute analytically the stationary distribution, which is exponential when the transition probability rates are balanced. In the second case we numerically show that the connected node states are correlated if close to the empty state; consequently, the empty states tend to cluster in the network. We introduce a soft threshold that prevents the node from receiving any particle above a maximum state value. We have an approximate solution for the one-step process, whereas the synchronous dynamics is studied numerically. The dynamical properties of these simple models can be related to the study of congestion formation in a transport network.

III

Flash

## RESILIENCE OF TRANSPORTATION NETWORK TO ROAD FAILURES

Jonas Wassmer

Damages to road infrastructure can cause disruptions in transportation and obstruct access to emergency services. With anthropogenic climate change increasing the probability of extreme weather events, the necessity for a resilient road infrastructure gets even more important. In our research, we identify roads that play a crucial role in maintaining the stability of the transportation network. To this end we develop a framework that is built on a traffic-based centrality measure that can be interpreted as individual vehicles traversing the network. The benefit of this framework is that it exclusively depends on openly accessible data sources such as OpenStreetMap, hence making it straightforward to apply and extend to different geographic locations of varying scales. As a case study, we analyse the impacts of the Ahr valley flood in Germany in 2021.

IV

Flash

## MEASURES OF NODE IMPORTANCE IN URBAN PUBLIC TRANSPORT NETWORKS

Tina Šfiligoj

I will present node centrality measures for different graph representation of urban public transport networks. An overview of the most commonly used measures, such as degree, closeness, betweenness and eigenvector centality will be given. In the second part I will focus on graph energy and graph entropy related centrality measures, as related to urban public transport accessibility and robustness, which will be the focus of my research.

V

Full

## EXPANDING STATISTICAL METHODS FOR NETWORK TOPOLOGY ANALYSIS

Bernat Salbanyà

Network analysis is widely used in various research fields, but assessing the statistical significance of observed relationships in networks remains challenging. Traditional permutation tests are often insufficient in capturing the effect of changing network topology. This research addresses this gap by proposing three alternative methods: shuffling, random rewiring, and controlled rewiring. These methods incorporate changes in the network topology through local permutations, allowing for more nuanced alterations while maintaining the original network interconnectivity distribution. We provide practical tools for calculating and interpreting these tests, using real-world examples, mainly focusing on the network structure of the Enron Corporation. The relevance of the proposed methods lies in their applicability to networks with extreme relationship distributions and scale-free networks. These methods protect researchers against Type I errors when analyzing network measures that depend on topologies, like centrality measures or clustering coefficients.

VI

Full

## GENERATIVE MODEL FOR POWER GRID SYNTHETIC NETWORKS

Alessandra Corso

We propose a generative model in order to create synthetic random networks with topological properties of real-world power grids. We studied five European power grids specifically focussing on four network topology measures: average shortest path length, clustering coefficient, mean degree and local maximum degree. The algorithm we wrote for this work takes as input the synthetic network degree distribution, obtained with a random sample built from real network degree distributions, and it outputs the synthetic network adjacency matrix. In my talk, I will introduce the literature about generative models and synthetic complex systems. Successively, I will explain in greater detail our generative algorithm synthetizing random networks with real-world power grids topological properties.

# LOCATION

The School will take place in **“Hotel Nettuno”**
**(Viale Ruggero di Lauria, 121- 95127 Catania - CT Sicilia)**.

The fee includes accommodation in a sigle room with bathroom, available from June 25 2023 to June 30 (night) included. Attendants who wish to arrive before, or leave after, these dates should arrange for other accommodation on their own.

Breakfast is provided by the school.
Refreshments will be available during the morning sessions and are included in the fee.
**Participants are responsible for arranging their own lunches and dinners**. However, they have the option to enjoy a typical Sicilian lunch and dinner at the hotel for a special price of €30 per person per meal (set menu, three courses chosen from the daily menu, including water and coffee, excluding wine and other beverages). NOTE: Those who prefer not to have lunch at the restaurant may choose to have a quick snack at our Pool Bar.

**How to get to “Hotel Nettuno”:**
Located in Viale Ruggero di Lauria 121, about 9 km away from the "Vincenzo Bellini" Fontanarossa Airport, it is possible to reach it quickly once landed.

At the exit of the airport you will find **Alibus**, a shuttle that will take you to the Catania railway station where you have to take **Bus 448**.

The attendants can purchase the ticket on board.

to Hotel Nettuno, Viale Ruggero di Lauria, 121, 95...

Walk
About 6 min, 450 m

7:50 PM **Capolinea ALIBUS**

ALIB Giovanni XXIII Stazione Centrale
20 min (4 stops)

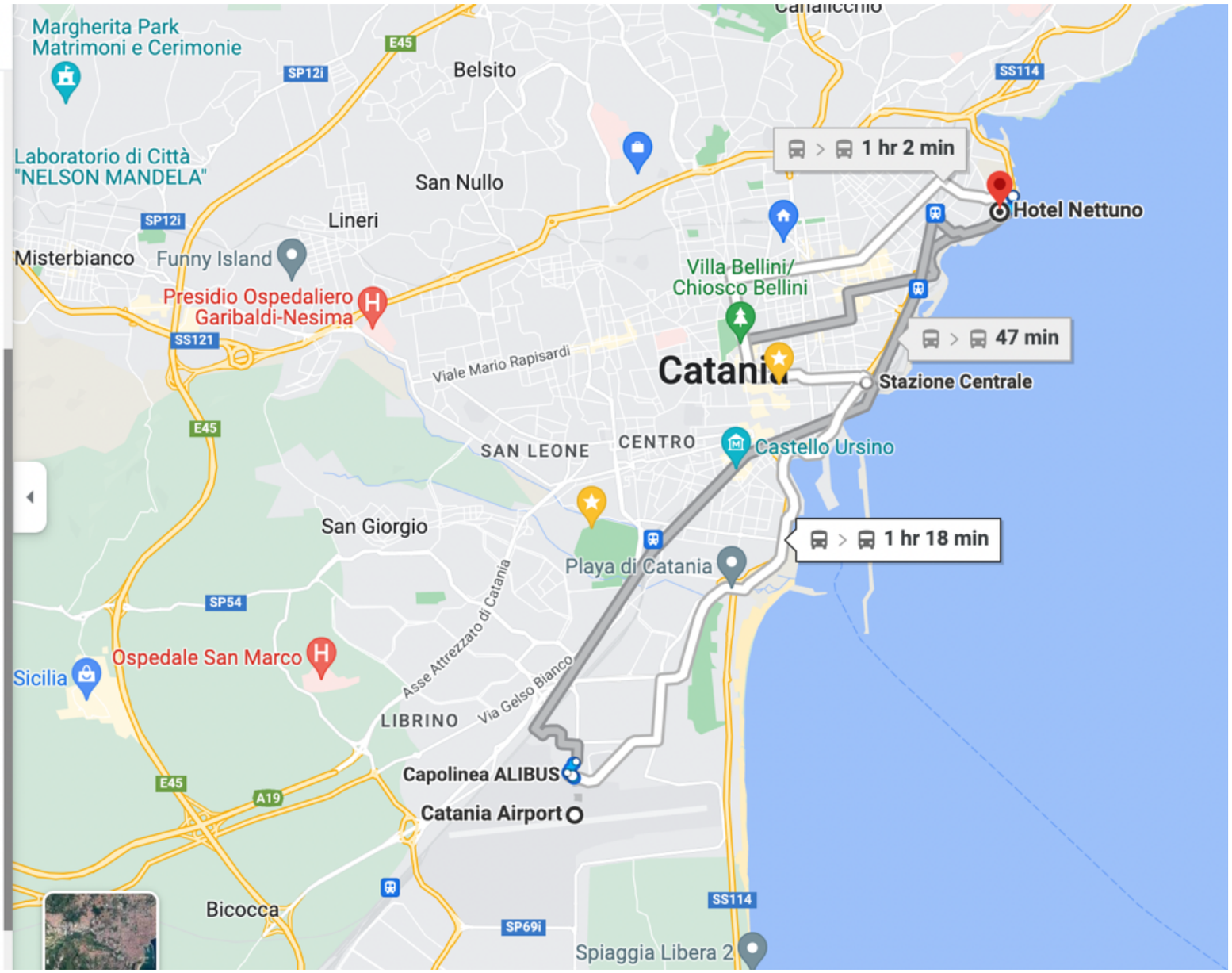
8:10 PM
8:25 PM **Stazione Centrale**

448 Harris Messina
34 min (26 stops)

8:59 PM **Alagona Nettuno Est**

Walk
About 3 min, 250 m

9:02 PM **Hotel Nettuno**
Viale Ruggero di Lauria, 121, 95127
Catania CT




**For more informations:** Alibus https://www.amts.ct.it/alibus. Hotel Nettuno https://www.hotel-nettuno.it

# MAP OF CATANIA AIRPORT

# ETNA VOLCANO TOUR

**Location:** south side of Etna

**Altitude:** 2000 Meters

**Duration:** from 15:00 to 22:00

**Difficulty:** medium-easy

Etna represents a natural, terrestrial scientific laboratory, and its volcanic zones and intense eruptions have been observed and talked about since Antiquity.

This evening excursion on Etna will allow you to admire the magnificent colors of the evening in the splendid setting of the extinct craters of the volcano!

*Mount Etna volcano in Sicily*

**Requirements**

It is strongly recommended not to participate in the excursions to people who are not in good health, especially those ones suffering from cardiorespiratory diseases.

**Recommended equipment**

We remind you to wear closed and sturdy shoes (sports or trekking) with thick socks, and to bring a winter-like jacket because the temperature at high altitude can be lower, especially at night (about 5-7 °C).

**For more informations**

https://lovingsicilia.it/vulcano-etna-sicilia/crateri-silvestri-rifugio-sapienza/

https://sicilia-etna.it/vulcano-etna/passeggiate-sull-etna/passeggiata-crateri-silvestri/

https://www.youtube.com/watch?v=FM1dj0s9Ghk

**The relationship between Etna and Man**

The volcano, apparently so hostile to settlements, has always offered a variety of resources that seem designed specifically for human needs since prehistoric times. Etna makes its entry into the literature thanks to the Greeks with the eruption of 475 BC. Pindaro is described it in the mythical image of Typhoeus or Typhon. A giant who wandered in the volcanic areas, which, imprisoned by Zeus under the weight of the volcano, spat fire from his eyes and nostrils. With time, the myths and legends ended, but the eruptions continued to leave their traces and to modify the volcano. But if you are wondering why do people live close to active volcanoes, you should know that the main reason is the rich volcanic soil. The region has been intensively cultivated for centuries. The land is planted with vines, vegetables and flowers. Every square foot of this rich soil is used.

Photos of the Etna tour of the VII edition

# SOCIAL DINNER

**Location:** Dimora De Mauro

**Duration:** From 20:00 to  23:00

**Meeting point:** Piazza Duomo at 20:00
(the transfer is self-organized by the attendant)

**How to get to "Piazza Duomo”:** Bus **534** From Lauria to Stesicoro**.**

**Informations:** https://museodiocesanocatania.com/

da Hotel Nettuno, Viale Ruggero di Lauria, 121, 95...
a Piazza del Duomo, 95100 Catania CT

## 19:01 (giovedì) – 19:27
(26 min)

534 >

19:03 da Lauria
10 min

Aggiungi al calendario

**19:01** **Hotel Nettuno**
Viale Ruggero di Lauria, 121, 95127 Catania CT

A piedi
Circa 2 min, 210 m

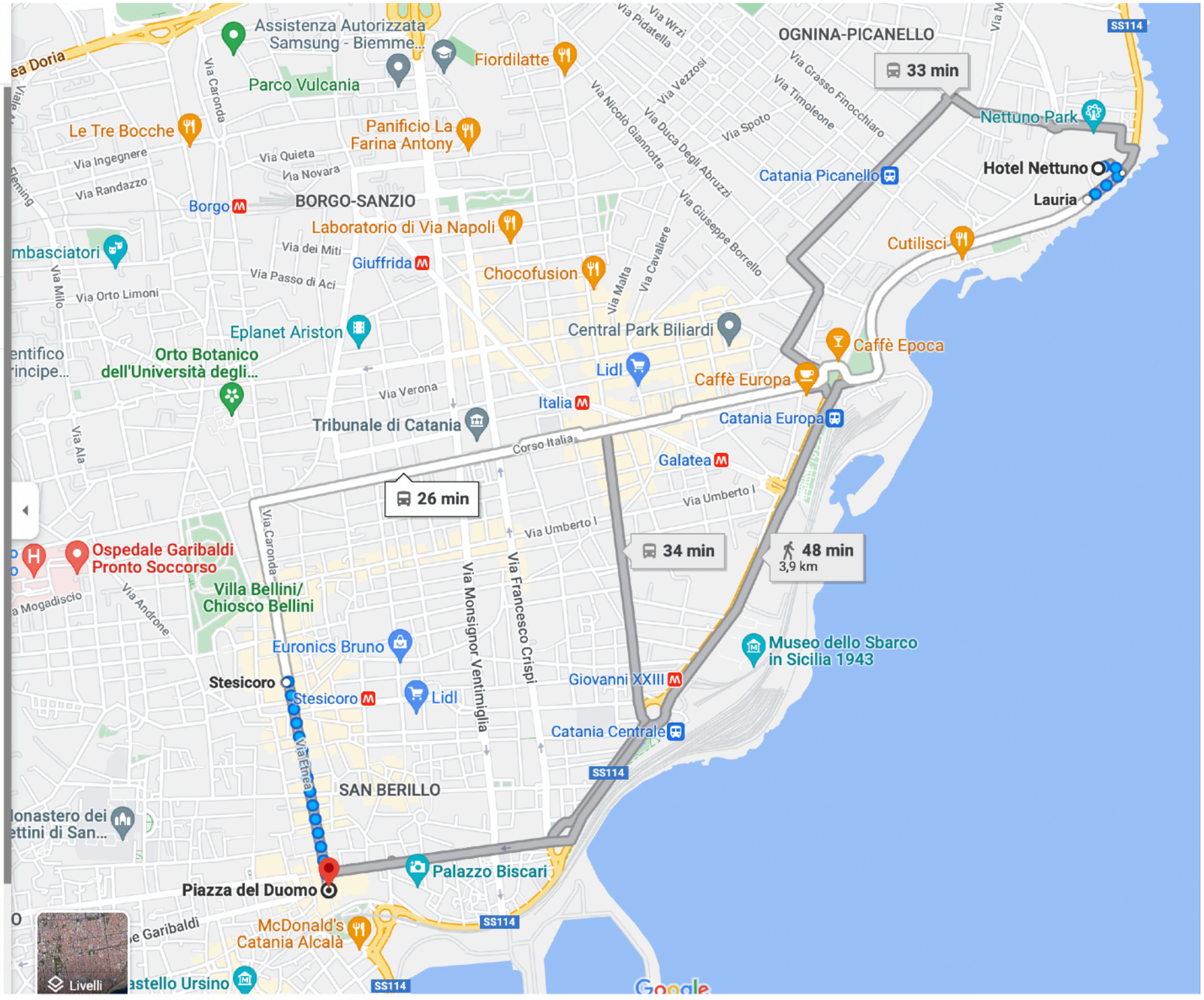
**19:03** **Lauria**

534 Terminal Borsellino Ovest
16 min (12 fermate)

**19:19** **Stesicoro**

A piedi
Circa 8 min, 650 m

**19:27** **Piazza del Duomo**
95100 Catania CT



# SPONSORS

COMPLEX SYSTEMS SOCIETY

Università degli studi di Padova

Università degli studi di Catania

Universitat Rovira i Virgili

MSCx networks