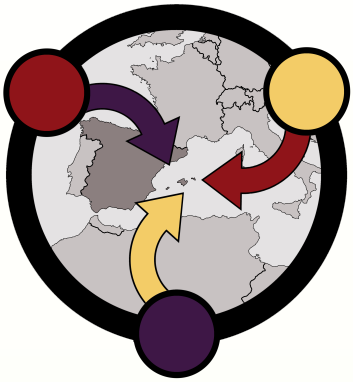

Winter Workshop on Complex Systems

2026

Book of Abstracts

Mallorca, Spain
25–30 January 2026

Cover background:
A Cartography of Arrival

At a certain hour of the day,
from an institution a certain distance away,
you pressed "submit" and became part of WWCS.

That moment is frozen here as a point:
time on one axis, distance on the other,
patience encoded in size.

Colours mean something.
Do you know what?

Look closely… do you see yourself?

EXCELENCIA MARÍA DE MAEZTU 2023 - 2027

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Organisers' Welcome

Welcome to the eleventh edition of the Winter Workshop on Complex Systems (WWCS)!

During this year of organization, this workshop has become more than just a scientific event for us and marks a milestone in our calendar. It is therefore a great pleasure to welcome you, and we want to start by sincerely thanking all participants for being here. We know that as early-career researchers, your days are packed: papers to read, algorithms to code, classes to teach, conferences to attend, theses to write, and the constant pressure to publish. That's why it means so much that you've chosen to spend your time with us. Your curiosity, energy, and willingness to connect across disciplines are what give WWCS its life and spirit, shaping the workshop year after year.

WWCS is more than a scientific meeting. It all started in 2014, when a small group of young researchers created a space inspired by the collaborative spirit of the Santa Fe Institute Summer School. Since then, the workshop has grown into a vibrant international community. One of its most distinctive features is that it is organized *by* early-career researchers *for* early-career researchers. Each generation of organizers passes the baton to the next, transforming previous attendees into future organizers. For us, the Organizing Committee, it has been an honour to be entrusted with this responsibility and to serve as the next link in the chain. In this sense, WWCS has become a scientific family, growing steadily thanks to the interest and commitment of the complexity science community, of which all of us are an essential part.

The primary goal of the workshop is to foster new scientific collaborations and encourage the exchange of ideas across disciplinary boundaries. Over the years, many projects initiated here have developed into successful long-term collaborations; therefore, we hope that this edition will be equally fruitful, providing an environment where creativity, independence, and curiosity can thrive. At the same time, WWCS has always been about people as much as it is about science. By bringing together participants from diverse backgrounds and research traditions, the workshop aims to build connections that last far beyond the week we spend together. History shows these connections can be surprisingly enduring, sometimes even leading to marriage! Who knows what kinds of partnerships, scientific or otherwise, this edition might inspire?

We would also like to express our deep gratitude to our invited speakers: Rafael Prieto-Curiel, Carmen Cabrera, Luis F Seoane, and Maxi San Miguel. Their contributions help ensure a stimulating and supportive research environment for all participants.

Finally, we gratefully acknowledge the generous support of our sponsors. Their collaboration makes this workshop possible and allows us to provide grants to participants, enhancing WWCS's accessibility and inclusivity.

We hope that your experience at the Winter Workshop on Complex Systems will be both scientifically rewarding and personally enriching, and that the ideas, collaborations,

and friendships formed here will continue to grow long after the workshop has ended.

We wish you a productive and, above all, enjoyable workshop!

Sincerely,

The Winter Workshop on Complex Systems Organizers:

Organizing Committee

Andrés Guzmán
Elena García de Lamo
Jaume Llabrés Rubio
Leonardo Federici
Pedro Jiménez González
Sara Oliver Bonafoux

Steering Committee

Emma Fraxanet
Elena Candellone
Fernando Diaz Diaz
Miguel Ángel González Casado
Ariadna Fosch Muntané
Adam Finnemann
Natalia Briñas-Pascual
Sara Linde Neven
Pablo Rosillo-Rodes
Irene Ferri

Our Speakers

Rafael Prieto-Curiel

Complexity Science Hub

Rafael Prieto-Curiel is a Faculty Member at the Complexity Science Hub, where he works on topics including violence, mobility, migration, and urban dynamics. He works for the OECD and the World Bank, conducting spatial and demographic analyses of cities. He is the Scientific Advisor of Aleph. In 2024, he was awarded the "Science Breakthrough" award by the Falling Walls Foundation.

Previously, he was at the Mathematical Institute of the University of Oxford, working on urban dynamics as part of the Peak Urban project. He earned an MSc in Statistics and a PhD in Mathematics and Security and Crime at UCL. He also worked in the Emergency Attention Centre in Mexico City (C5) as Director of Strategic Analysis, where his work primarily consisted of crime forecasting and police and resource allocation.

Luis F Seoane

Universitat Pompeu Fabra & CSIC

Luis F Seoane is a researcher in Complex Systems—working in that field in a very general sense. He has contributed studies to computational neuroscience, evolutionary dynamics, network theory, econophysics, or linguistics—among others. Very often, these studies tackle how a system's complexity is changed as the system varies in size, number of components, number of parts, etc; and vice-versa: how a system's complexity might affect its growth and constituting units. Since July 2025, he works at the Institute for Evolutionary Biology (IBE, UPF-CSIC) in Barcelona, where he heads the BIT Lab. Earlier, he completed postdocs at MIT, IBE, the Institute for Interdisciplinary Physics and Complex Systems (IFISC) in Palma de Mallorca, and the Spanish National Center for Biotechnology (CNB, CSIC) where he first launched the BIT Lab in 2023.

Carmen Cabrera-Arnau

University of Liverpool

Carmen Cabrera is a Lecturer in Geographic Data Science (Assistant Professor) at the Geographic Data Science Lab, within the University of Liverpool's Department of Geography and Planning. Her areas of expertise are geographic data science, human mobility, network analysis and mathematical modelling. Carmen's research focuses on developing quantitative frameworks to model and predict human mobility patterns across spatiotemporal scales and population groups, ranging from intraurban commutes to migratory movements. She is particularly interested in establishing methodologies to facilitate the efficient and reliable use of new forms of digital trace data in the study of human movement.

Prior to her position as a Lecturer, Carmen completed a BSc in Physics, followed by an MSc in Complex Systems, specialising in Network Analysis. She then did a PhD in Applied Mathematics at University College London (UCL), focusing on the development of mathematical models of social behaviours in urban areas, against the theoretical backdrop of agglomeration economies. After graduating from her PhD in 2021, she was a Research Fellow in Urban Mobility at the Centre for Advanced Spatial Analysis (CASA), at UCL, where she currently holds a honorary position.

Maxi San Miguel

Universitat de les Illes Balears, IFISC

Maxi San Miguel (PhD in Theoretical Physics, University of Barcelona 1978) is Professor of Physics at the University of the Balearic Islands-UIB (since 1986) and founding Director of IFISC (Institute for Cross-Disciplinary Physics and Complex Systems, UIB-CSIC(Spanish National Research Council), Palma de Mallorca, Spain. His academic career include positions and appointments at University of Barcelona, Temple University (Philadelphia, PA, USA), Università di Roma La Sapienza, University of Arizona (Tucson, AZ, USA), University of Strathclyde (Glasgow), University of Technology of Helsinki and the Complexity Sciences Hub, Vienna. His research activity spans across different fields of Statistical and Nonlinear Physics (Stochastic Processes, Phase Transitions, Pattern Formation and Spatio-temporal Complexity, Complex Networks) and Computational Social Science, as well as Laser Physics and Photonics. He is the author of over 360 papers quoted over 18,600 times (h index=65) in top journals of Physics, Engineering, Ecology, Social Science and Multidisciplinary Science.

Maxi San Miguel was coordinator for Physics and Mathematics of ANEP (Spanish National Evaluation Agency), chairman of the EPS (European Physical Society) Division on Statistical and Nonlinear Physics (1998-2002), and vice-chair of the IUPAP (Interna-

tional Union on Pure and Applied Physics) commission on Statistical Physics (2017-20). Maxi San Miguel has received the Medal of the Spanish Physical Society-Fundación BBVA in 2010 and the Senior Scientific Award 2015 of the Complex Systems Society.

Schedule

The workshop combines invited keynote lectures, participant-led tutorials, and collaborative group projects, alongside social activities designed to encourage interaction and networking. The scientific program will conclude with project presentations on the final day.

Lectures: The workshop will feature three keynote lectures by Rafael Prieto-Curiel, Carmen Cabrera-Arnau, and Luis F Seoane, each lasting 90 minutes, plus a closing lecture by Maxi San Miguel.

Tutorials: Three participant-led tutorials are planned, each lasting about 45 minutes.

Projects: Participants will work in groups to formulate research questions and develop preliminary results, which will be presented on the final day.

Social Activities: The program also includes non-academic activities such as a social event in Palma de Mallorca, a hiking excursion in the Tramuntana mountains, stargazing (weather permitting), wine tasting (with non-alcoholic options available), and evening group activities.

	Expected hours
Projects	22h
Lectures	5h 30min
Other activities	7h

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
9:00	**Arrival to Palma** 8:00 - 12:00	**Breakfast** *Sa Fonda* 8:00 - 9:00	**Breakfast** *Sa Fonda* 8:00 - 9:00	**Breakfast** *Sa Fonda* 8:00 - 9:00	**Breakfast** *Sa Fonda* 8:00 - 9:00	**Breakfast** 8:00 - 8:30
		Introduction & presentation *RM Santa Figura* 9:00 - 10:00	**Invited speaker: Rafael Prieto-Curiel** *RM Santa Figura* 9:00 - 10:30	**Invited speaker: Luís F Seoane** *RM Santa Figura* 9:00 - 10:30	**Invited speaker: Carmen Cabrera** *RM Santa Figura* 9:00 - 10:30	**Bus back to Palma** 8:30 - 10:00
10:00		**Coffee break** 10:00 - 10:30				**Closing session: Maxi San Miguel** *Ca n'Oleo* 10:00 - 11:00
			Coffee break 10:30 - 11:00	**Coffee break** 10:30 - 11:00	**Coffee break** 10:30 - 11:00	
11:00		**Project discussion** *RM Santa Figura* 10:30 - 13:00	**Student tutorial** *RM Santa Figura* 11:00 - 13:00	**Hiking + Lunch** *Serra de Tramuntana* 11:00 - 14:00	**Projects** 11:00 - 13:00	**Coffee break** 11:00 - 11:30
12:00	**Social Lunch** *Casal de Barri Es Jonquet* 12:00 - 16:00					**Project presentations** *Ca n'Oleo* 11:30 - 14:00
13:00		**Lunch** *Sa Fonda* 13:00 - 14:00	**Lunch** *Sa Fonda* 13:00 - 14:00		**Lunch** *Sa Fonda* 13:00 - 14:00	
14:00		**Project** 14:00 - 18:00	**Student tutorial** *RM Santa Figura* 14:00 - 15:00	**Project** 14:00 - 18:00	**Project** 14:00 - 18:00	**Closing event (optional)** 14:00 - 17:00
15:00			**Project** 15:00 - 18:00			
16:00	**Bus to venue location** 16:00 - 18:00					
17:00						
18:00	**Free Time** 18:00 - 20:00	**Free Time** 18:00 - 20:00	**Stargazing** 18:00 - 20:30	**Wine Tasting** *RM Teatre* 18:00 - 20:00	**Free Time** 18:00 - 20:00	
19:00						
20:00	**Dinner** *Sa Fonda* 20:00 - 21:00	**Dinner** *Sa Fonda* 20:00 - 21:00	**Dinner** *Sa Fonda* 20:30 - 21:30	**Dinner** *Sa Fonda* 20:00 - 21:00	**Dinner** *Sa Fonda* 20:00 - 21:00	
21:00	**Introduction game** 21:00 - 22:00	**Games and other activities** 21:00 - 22:00	**Free Time** 21:30 - 22:00	**Free time** 21:00 - 22:00	**Games and other activities** 21:00 - 22:00	

Contents

Keynotes talks

Tuesday 27, 9:00-10:30

How to model violence using complex systems?

Rafael Prieto-Curiel
Complexity Science Hub

Violence is often treated as a sequence of isolated events, but patterns suggest it emerges from interacting individuals, institutions, and environments. I will present a modeling framework to analyse different types of violence. Drawing on networks, dynamical systems, and agent-based models, I will show how to model crime and potential interventions, aiming to map strategies that can reduce harm.

Wednesday 28, 9:00-10:30

From Pareto Optimality to Topological Communities: tools for navigating complex systems with applications to language networks

Luis F Seoane
Universitat Pompeu Fabra & CSIC

All species posses some communication system, some of them quite complex. Human language is unique in several ways: (i) It provides infinite expressivity with finite means. (ii) It contains words, quite complex devices (different from indexes or signals from other animal systems) able to form associations independent of the objects involved. (iii) Words, and other linguistic elements, enable discussing situations not present (in space or time—including speculation about past, future, possibilities, and counterfactuals). (iv) Language enables a unique internal, hierarchical representation of the world. Etc. "Language" is too big to condense in short lectures, but its study through computational means is rich enough, and calls upon methods of relevance for Complex Systems at large. We will introduce some of this methodology through examples from my work in linguistics. We will open with a short introduction to human language, to motivate its study and why it fascinated so many people over the years. Then, issues of optimality in linguistic codes will serve as an excuse to explore Pareto (or multi-objective) optimization. We will see how Pareto optimality underlies phase transition and criticality in Statistical Physics, what this reveals about linguistic codes, and how this might be of relevance in other fields. Finally we will turn our attention to syntax networks. They will illustrate how methods from dimensionality reduction help us extract insights about evolution and development. We will see how these methods are generally useful across networked systems—a field ripe with potential in which dimensionality reduction has not made a stride yet.

Thursday 29, 9:00-10:30

Challenges of digital trace data in the study of collective behaviour

Carmen Cabrera
University of Liverpool

The rise of digital trace data (e.g. social media activity, mobile phone location records, etc.) has revolutionised how we observe and model collective behaviours, by providing unprecedented resolution in space, time and scale. This data allows us to gain new evidence and knowledge in complexity science, but it also exposes a trade-off between the abundance of information and reliability. In this talk, I will examine how uneven levels of engagement with digital platforms and inequalities in digital access across user groups influence the patterns and behaviours we infer. I will review recent methodological advances for identifying and understanding these data biases. My goal is to encourage a more critical and reflexive use of digital trace data, so that its growing influence leads to more credible and responsible science.

Closing session

Friday 30, 10:00-11:00

An open discussion on the frontiers of complex systems

Maxi San Miguel
IFISC-UIB

The closing session on Friday will be led by Prof. Maxi San Miguel (IFISC) and will focus on his paper “Frontiers in Complex Systems”. In the article, he discusses what complex systems are and outlines some of the main current research challenges in the field. Maxi will give a short introduction (around 15 minutes), followed by an open discussion where everyone is welcome to share their thoughts. We strongly encourage you to read the paper in advance and take part in the debate. We believe it will be a very enriching discussion for the whole community. You can find the paper here.

Tutorials

Tuesday 27, 11:00 - 11:45

Webscraping your way out of getting data

Juan Antonio García Castillo
IFISC

This tutorial is intended to be an introduction to web scraping, which is defined as an automatic way of obtaining large amounts of data from websites. If done ethically and legally, it can be a powerful tool for your research, especially when the data you need is not readily available in a clean or downloadable format. In this session, we will cover the basics behind web scraping, as well as the usage of some basic libraries in Python that are needed to perform basic web scraping techniques, such as “BeautifulSoup” or “requests” to extract text from the HTML code of the website, and others like "re" to operate with large and unstructured text. We will perform the analysis on different websites in real time and, by the end of the session, participants will (hopefully!) be able to scrape, clean, and structure basic web data for further analysis in a clear and approachable way.

Tuesday 27, 12:00 - 12:45

Critiques of complexity: an attempt at fostering critical thinking of our own epistemological tools

Eider Pérez-Ordoyo
Universitat Pompeu Fabra

This will not be your usual tutorial into how to use Python, data analysis tools or networks. In this tutorial, I intend to open a space to talk and question the practices done in the study of complex systems and complexity science in general. Are we truly interdisciplinary? Are our mathematical and conceptual tools helping or hindering the disciplines we work in? Are we using said tools from a specific philosophical standpoint? Does this affect how we use them? What narratives do we create? And many more!
Because, what is science if we don’t question what we do?

Tuesday 27, 14:00 - 14:45

Spreading processes on networks with 10 million nodes (and beyond)

Juliane Teixeira de Moraes
Universitat Politècnica de Catalunya

Spreading phenomena have attracted significant attention in recent years, particularly following the COVID-19 pandemic. Since complex networks provide a natural framework to represent social interactions, network-based modeling has played an important role in epidemic surveillance and analysis. Moreover, spreading processes on complex networks are a long-standing research topic and have been extensively studied, especially from the perspective of statistical physics. Celebrated models, as the contact process, for instance, are known to exhibit rich behavior concerning phase transitions. This tutorial aims to provide an introduction to the statistical physics of spreading phenomena on large-scale networks, with a particular emphasis on finite-size scaling analysis. Practical aspects of simulating epidemic models on networks with up to 10 million nodes (and larger) will be discussed, highlighting computational strategies and performance considerations.

Posters

Modeling medium and low voltage grids using population density

Emile Emery, Joseph Le Bihan & José Halloy
Université Paris Cité, CNRS, LIED UMR 8236, Paris, F-75006, France

The expansion of global electricity distribution systems necessitates the deployment of massive infrastructure. Assessing its implications from a spatial and material perspective requires an understanding of the core drivers of a distribution grid configuration. Our model samples substation locations using a non-linear relationship with population density and constructs the network applying the Kruskal algorithm. This streamlined approach generates realistic grid structures at the local scale and provides accurate estimates of the total network length at the national scale. Using highly granular population data, this local model reveals a profound connection between population spread and distribution grid, which appears to persist at the global level. Potentially driven by the emergent properties of population scaling laws, the full network characteristics appear to be well described by multivariate power laws on aggregated population and area. Validated across 35 countries, these results provide new multi-scale tools for characterizing electrical infrastructure and reveal key determinants of distribution grid extent.

Clogging in evacuations through a narrow opening: decoupling speed and pushing

Marta Grasa, Angel Garcimartín, Laciel Alonso-Llanes & Iker Zuriguel
Universidad de Navarra

It is common for clogs to form when many particles attempt to pass through a narrow opening simultaneously. In fact, it has been observed that a higher desired speed for the particles results in longer evacuation times. This is known as the Faster-Is-Slower effect. However, in most systems the desired speed of the particles is very closely related on the force they exert on the clogs when pushing towards the exit. We perform evacuation drills with self-propelled, programmable robots to decouple these two variables and gain better understanding on what makes evacuations less efficient.

Analysis of extreme events in time series through visibility graphs

Juliane T. Moraes & Cristina Masoller
Universitat Politècnica de Catalunya

Extreme events are characterized by significant deviations of an observable from its long-term average and are often associated with severe consequences for the underlying system. This topic has attracted increasing attention due to its strong impact across diverse systems, from climate dynamics to brain activity. Extreme events can be investigated through time series analysis. An approach in this direction is the visibility graph method. It consists of mapping a time series onto a graph structure, in which each point corresponds to a node, and pairs of nodes are connected if they satisfy a geometric visibility criterion. The visibility graph is known to preserve important characteristics of the original dynamics and is therefore applied in a wide range of time series analysis contexts. In this work, we present a framework to characterize extreme events in time series using visibility graphs. Unlike threshold-based approaches, extreme events in this framework arise naturally, without the need to introduce external parameters. Given a time series containing extreme events, we construct the visibility graph and rank the nodes, together with their corresponding time-series values, by degree and amplitude. Plotting these quantities against each other, we obtain the local extreme events, which, even if not associated with the largest amplitudes, exhibit a high degree due to their temporal neighborhood and may therefore represent relevant points in the analysis of the underlying dynamical system. Our forthcoming analysis includes the use of visibility graphs to anticipate the occurrence of extreme events.
Funding: Agencia Estatal de Investigación, Spain, project number PID2024-160573NB-I00

Instanton theory and fluctuation corrections to the nucleation rate of a ferromagnetic superfluid

Enrique Rozas Garcia & Johannes Hofmann
University of Gothenburg

We evaluate the nucleation rate for a ferromagnetic superfluid, a recent quantum-gas analogue of false-vacuum decay. The nucleation rate follows an Arrhenius-like law, where the leading exponential suppression is determined by a saddle point of the energy functional, and fluctuations around this saddle point determine the rate's prefactor. We compute both contributions over the full parameter space, using a Gel'fand–Yaglom approach to evaluate the fluctuation contribution. From this analysis, we identify a region of parameter space where closed-form results are available, and the nucleation problem simplifies to the Kramers escape for a single coordinate representing the size of a nucleating domain. Our results determine the dependence of the various contributions to the nucleation rate on experimental parameters, and facilitate a rigorous comparison between experiment and theory.

Stochastic dynamics of schooling fish

Elena G. de Lamo, M Carmen Miguel & Romualdo Pastor-Satorras
Universitat Politècnica de Catalunya
Universitat de Barcelona

Social animals often form groups in which interactions between individuals serve as the primary mechanism for coordination. One of the fundamental aspects of this coordination in many species is the maintenance of spatial cohesion, which is essential for navigating complex environments. Consequently, the confinement resulting from cohesion plays a significant role in shaping the internal dynamics of social animal groups, which are not static but evolve over time. This study aims to investigate the effects of cohesion in fish schools of varying group sizes, focusing on intermediate sized groups, with the goal of identifying universal patterns across different groups. Furthermore, we propose a model based on stochastic equations that captures the key characteristics of fish school behaviour. In developing the model, we demonstrate that the movement of fish can be described by a system of Langevin-type stochastic differential equations, a well-established approach in the study of animal movement. The stochastic forces are inferred from experimental data using kernel-based regression, which enables robust estimation of the drift and diffusion terms. This methodology has been successfully applied in other biological studies. Our findings suggest that the cohesion of fish schools can be modelled as the result of individual fish swimming freely, with a central force that acts to draw individuals back toward the group. This force is essential for maintaining the structural integrity of the school.

Participants

Adrián Gutiérrez Arroyo	University Carlos III of Madrid
Beatriz Arregui García	Fondazione Bruno Kessler
Bianca Pacini	Humboldt University Berlin
Carlotta Nunzi	IFISC - Institute for Cross-Disciplinary Physics and Complex Systems
Clara Eminente	Central European University
Duncan Cassells	Sorbonne Université
Eider Lumi Pérez-Ordoyo Bellido	Universitat Pompeu Fabra
Eleonora Gatti	University of Konstanz
Emile Emery	CEA
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Gabriella Lima Tabet Cruz	Universidad Complutense de Madrid
Giovanni Tagliani	University College London
Giulio Bettio	Ca' Foscari University of Venice
Joe Simpson	Stockholm Environment Institute; University of York
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