Book of Abstracts

XIX Workshop de Jóvenes Investigadores

The talks will be held in the room Miguel de Guzmán at the Faculty of Mathematical Sciences of the Universidad Complutense de Madrid

September 22-24, 2025

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Abstracts

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Degenerations of Hodge structures via period mappings

The main objective of this talk is to treat variations of Hodge structures. Even though this is done in the abstract setting one always should think that we are dealing with the cohomology of a family of smooth projective varieties $X \to S$. In this geometric picture, the broad question we want ask is how a possible degeneration of the family affects the variation.

There are many different ways of treating this problem. We explain how to translate it to the setting of period domains, which are certain flag varieties that "parametrize" Hodge structures. In this context the two most important classical results are Schmid's Nilpotent and SL2 orbit theorems. This pair of theorems helps us understand the degeneration in a meaningful way. In partic- ular, we explain how we can use these results to construct the so called limiting mixed Hodge structure, which is a mixed Hodge structure on the cohomology of a regular fiber such that its weight filtration is determined by the logarithm of the monodromy action of the variation. In fact, these limiting mixed Hodge structures are shown to be equivalent to nilpotent orbits.

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Some comments about lineability and non-lineability

We give a brief account of some early and some recent results in the area now known as lineability and spaceability. Several examples, results and open questions shall be presented. This lecture is part of a joint work with Prof. Juan B. Seoane Sepúlveda.

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On the number of equations defining an algebraic subvariety

A deep question in Algebraic Geometry is to understand when a subvariety of codimension r in $\mathbb{P}^n$ can be determined (in a precise technical way) by exactly r equations. A celebrated conjecture by Hartshorne states that this is true if X is smooth and $r > \frac{2}{3}n$. One of the classical approaches, in the case of complex varieties, includes the use of the topological properties of the subvariety. In this talk, intended to be accessible for mathematicians of different backgrounds, we will review this problem in a more general framework.

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Moduli Spaces in Algebraic Geometry

In this talk we explore the modern approach to moduli theory through representability of functors. As key examples, we will study the representability of the Hilbert, Quot and Picard functors introduced by Grothendieck.

Many candidates to be the moduli space for some moduli problem are built by considering the action of an appropriate algebraic group on a certain scheme. For the resulting quotient to have good structure properties, we will introduce Geometric Invariant Theory (GIT) as developed by Mumford, which is a fundamental method to construct moduli spaces. As an application of GIT, we will study the moduli space of semistable coherent sheaves with fixed Hilbert polynomial.

On the other hand, the presence of nontrivial automorphisms on the studied objects prevents a fine moduli space to exist. In order to avoid this pathology, we will present the theory of algebraic stacks. This will allow us to construct a Deligne–Mumford stack as a solution for the moduli problem of stable curves.

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Hybrid Methods for Multiscale Reaction-Diffusion Models of Tumour Growth

Reaction-diffusion systems provide a fundamental framework for modelling spatially extended biological populations. When cell numbers are large, deterministic partial differential equations (PDEs) offer efficient approximations, but they fail to capture stochastic effects that dominate in regions of low density, such as the leading edge of an expanding tumour. Fully stochastic simulations can account for these fluctuations but are computationally prohibitive for large systems. Hybrid methods address this challenge by combining stochastic and mean-field descriptions within the same spatial domain.

We formulate a hybrid approach for multiscale models of tumour growth that extends classical hybrid reaction-diffusion schemes to incorporate both population-level noise and intracellular variability in proliferation. The method is based on a coarse-grained approximation of the age-structured model, assuming fast equilibration of the age distribution, which allows a consistent coupling between stochastic and mean-field regions. Within the mean-field domain, both demographic fluctuations and birth-rate noise are neglected, while in the stochastic domain they are explicitly represented.

This framework enables a detailed analysis of travelling wave solutions, which provide a natural description of tumour invasion. We show that stochasticity in proliferation rates, in combination with population-level noise, produces large fluctuations at the leading edge of the wavefront. These fluctuations are absent from the mean-field description and lead to significant variability in wave velocity. The results demonstrate that proliferation noise, rather than population noise alone, is central to the quantitative understanding of invasive tumour dynamics. The proposed hybrid method thus offers both computational efficiency and biological accuracy in the study of stochastic tumour growth.

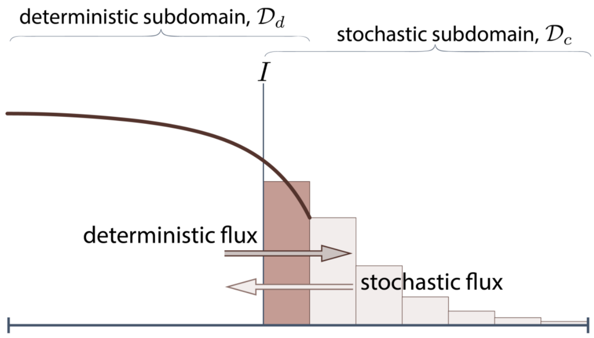

Figure 3.1: Schematic of a Hybrid Model Domain Division. The domain is divided into a deterministic domain and a stochastic domain separated by an interface (dark brown region). The deterministic flux and the stochastic flux indicate the transfer of particles across the interface, ensuring mass conservation and accurate coupling between the deterministic and the stochastic model

1. de la Cruz, R., Guerrero, P., Calvo, J., and Alarcón, T. (2017). *Coarse-graining and hybrid methods for efficient simulation of stochastic multi-scale models of tumour growth.* Journal of Computational Physics, 350, 974-991. https://doi.org/10.1016/j.jcp.2017.09.019

2. Spill, F., Guerrero, P., Alarcon, T., Maini, P. K., and Byrne, H. (2015). *Hybrid approaches for multiple-species stochastic reaction-diffusion models.* Journal of Computational Physics, 299, 429-445. https://doi.org/10.1016/j.jcp.2015.07.002

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Hodge Structures on Character Varieties

Given a finitely generated group Γ and an algebraic group G, we define the *G-character variety of* Γ as the moduli space of representations $\rho : \Gamma \to G$ of the group Γ into G. These kind of varieties have been widely studied because they provide us with a connection between different fields of mathematics such as Knot Theory and Algebraic Geometry, but also with Physics, since they play an important role in String Theory.

In this talk, we will show how these varieties are studied. In concrete, we will introduce the E-polynomial, an algebraic invariant that arises from the Hodge structure of the variety and that plays a prominent role in the study of a physical phenomenon called Mirror Symmetry and also in Knot Theory. We will introduce the different techniques used to compute this invariant, as well as some of the most important results obtained about it.

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Spaces of left-preorders on groups

A left-preorder on a group is a left-invariant total transitive reflexive binary relation. The aim of the talk is defining and studying some spaces of left-preorders. They are topological spaces that arise by endowing a natural topology on the set of left-preorders on a given group. These spaces generalize spaces of left-orders, which has been considered many times on the theory of orderable groups. The space of left-preorders on a free product has no isolated elements. In particular, when the group is finitely generated, this space is a Cantor set.

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Membrane systems with asymmetric Kedem-Katchalsky boundary conditions

This work studies a model of two species inhabiting adjacent subdomains of a bounded region, interacting solely through a permeable interface. Populations evolve according to logistic equations with spatial heterogeneities in growth and crowding, including refuge zones with unlimited resources. The interface is modelled via asymmetric Kedem-Katchalsky boundary conditions. The study examines the existence and behaviour of positive solutions depending on system parameters, identifying a lower bifurcation threshold for population emergence and an upper threshold linked to refuge areas. A non-simultaneous blow-up is observed, where only one population becomes unbounded in its refuge zone.

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Igusa zeta functions of hyperplane arrangements and wonderful models

Embedded resolution of singularities is a common tool for the computation of Igusa zeta functions of hypersurfaces. The theory of wonderful models of De Concini and Procesi constructs embedded resolutions for hyperplane arrangements. In this talk we will present these objects and show an explicit computation for the case of the (real) braid arrangement.

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The Zariski-Van Kampen theorem

Singularities of algebraic varieties are similar to knots in many ways. For this reason, many techniques and themes from the study of the latter get translated to the former, such as the study of the topology of the complement to understand the singularities. This gives rise to this problem: given a polynomial f(x,y) over the complex numbers, what is the fundamental group of the set $\{(x, y) \in \mathbb{C} : f(x, y) \neq 0\}$? We will give an overview of a method that produces a presentation of the fundamental group.

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Nonlinear and nonhomogeneous overdetermined problems

It is in general not possible to obtain solutions to PDE with more boundary conditions than needed (overdetermined problems). However, as we will explain in this talk, we have been able to find solutions to a very broad family of nonlinear PDE, which are moreover anisotropic and nonhomogeneous. We also show that these solutions are regular, and can have arbitrary large sizes.

To achieve this, we extend a very famous Calculus of Variations scheme (dating back to Alt and Caffarelli in 1981) which makes strong use of the modern theory of Partial Differential Equations. The major problem to overcome is the size of the domains: for small domains, perturbation from trivial solutions proved to be an useful technique in the last decade; but this technique is not available for large domains, which is our setting. This is based on a joint work with Alberto Enciso and Xavier Ros-Oton.

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Classification of functional Gaussian data with random trends

Functional data, such as curves or trajectories, are increasingly common in applications ranging from biomedicine to economics. A key statistical challenge is to classify such data into different populations. We focus on the case where the data are modeled by Gaussian processes. In the first class, observations follow a centered Gaussian process with covariance function KKK. In the second class, they are obtained by adding an independent Gaussian random trend with covariance RRR.

This framework captures situations where random effects or additional variability are present in the data. We provide a full characterization of the Bayes optimal classifier, describing when perfect classification (with zero error) is possible and when a nonzero error is unavoidable. Moreover, in certain cases the optimal rule admits simple explicit formulas. These results clarify how the presence of a random trend affects the ability to distinguish between populations and extend previous approaches to functional classification. This is joint work with José Ramón Berrendero and José Luis Torrecilla.

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The Takagi function and the shadowing property

Let $f : [0,1] \to [0,1]$ be a continuous function. For a given $\delta > 0$, a sequence $(x_n)_n$ is said to be a δ-*pseudo orbit* of f provided that

$$|f(x_n) - x_{n+1}| < \delta$$

for all $n \geq 0$.

The function f is said to have the *shadowing property* if for every $\varepsilon > 0$ there exists $\delta > 0$ such that for any δ-pseudo orbit (x_n) of f there is $x^* \in [0,1]$ such that

$$|f^n(x^*) - x_n| < \varepsilon$$

for all $n \geq 0$.

The Takagi function $T : [0,1] \to [0,2/3]$ is a classical example of a continuous nowhere differentiable function. The Takagi family consists of all the maps

$$\mathbf{T}_\gamma : \left[0, \frac{2}{3} \cdot \gamma\right] \to \left[0, \frac{2}{3} \cdot \gamma\right],$$

where $\gamma > 0$, defined by $\mathbf{T}_\gamma = \gamma \cdot T$.

In this talk, we prove that the Takagi function has the shadowing property. Furthermore, we also determine values of the parameter γ for which the function $\mathbf{T}_\gamma$ does not have the shadowing property. This is done by studying two distinct geometric properties satisfied by the Takagi function at certain points, thereby revealing new geometric features of the function.

1. Z. Buczolich and J. Llorente, *Dynamics of the Takagi function and the shadowing property*, preprint 2025.

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Bohnenblust–Hille inequality and applications in learning theory

Boolean functions, defined on the hypercube $\{-1,1\}^n$, play a central role in many areas of mathematics and theoretical computer science. However, in many relevant situations, the governing function is unknown: we do not have direct access to it, but only to a limited number of examples. This raises the fundamental problem of how to reconstruct or approximate an unknown function from partial information. This is precisely one of the central questions addressed in learning theory.

In this talk, we will discuss some analytical tools used to tackle this problem, such as hypercontractivity and Blei's inequality. Building on these, we establish a discrete version of the Bohnenblust–Hille inequality, a classical result in the analysis of Dirichlet series which, in this context, provides precise control over the $\ell^{\frac{2d}{d+1}}$ norm of the Fourier coefficients of any function defined on the cube, and hence over its spectral behavior.

Finally, we explore possible connections with open problems in quantum information theory; in particular, with the Aaronson–Ambainis conjecture, a deep proposal that sets fundamental limits on quantum advantage.

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The NEC group uniformization of extremal hyperbolic surfaces

An important geometric feature of hyperbolic surfaces, ie. the topological surfaces whose universal covering space is the hyperbolic plane, is the largest radius of a metric disc properly embedded in a given surface, known as its *injectivity radius*. In 1996, C. Bavard [1] showed that the maximal injectivity radius of any compact orientable hyperbolic surface without boundary is sharply bounded above by a certain *extremal radius* that depends only on the topology of the surface. This upper bound was later generalized for non-orientable closed hyperbolic surfaces and, in the following years, several authors studied the closed hyperbolic surfaces that contain an embedded metric disc of that extremal radius, the so-called *extremal surfaces*, by using the uniformization of hyperbolic surfaces by NEC groups.

However, in the last decade, a different approach has been proposed by J. deBlois and K. Romanelli, which has been essential in determining the precise dependence of the extremal radius of any hyperbolic surface of finite type (which may have punctures and/or geodesic boundary) with respect to the underlying topology of the surface.

In this talk, after a brief introduction to the theory of closed extremal surfaces, I will translate the results of deBlois and Romanelli back into the language of the uniformization by NEC groups and I will apply this different point of view for counting the total number of extremal surfaces given their topological data.

Joint work with Ernesto Girondo.

1. C. Bavard (1996). Disques extrémaux et surfaces modulaire. *Annales de la faculté des sciences de Touluse: Mathématiques*, Serie 6, Volume 5, no. 2, pp. 191-202.

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Searching for vanishing cycles in plane curves

In this talk, we will introduce the concepts necessary to understand what the geometric vanishing cycles of a Milnor fiber of a plane curve singularity are. We will explain their importance in singularity theory and, if time permits, we will characterize them in terms of a vanishing line integral (joint work with Nick Salter).

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Almost Continuous Sierpiński–Zygmund Functions: Existence, Lineability, and Set-Theoretic Contexts

Sierpiński–Zygmund (SZ) functions are classical pathological objects in real analysis, discontinuous on every subset of the reals of cardinality continuum. Their interplay with *almost continuous* (AC) functions—a class where the graph can be approximated by that of a continuous function—has led to deep questions at the boundary of real analysis and set theory. It is known that examples of $\mathrm{SZ} \cap \mathrm{AC}$ functions cannot be constructed in ZFC alone, but may exist under additional hypotheses such as the covering of category $\mathrm{cov}(\mathcal{M}) = \mathfrak{c}$, where $\mathfrak{c}$ denotes the cardinality of the continuum.

In this talk, I will present recent progress showing that $\mathrm{SZ} \cap \mathrm{AC}$ functions also exist under the opposite assumption $\mathrm{non}(\mathcal{N}) < \mathrm{cov}(\mathcal{N}) = \mathfrak{c}$, thereby disproving the conjectured equivalence between $\mathrm{cov}(\mathcal{M}) = \mathfrak{c}$ and the existence of such functions. I will discuss their consistency with ZFC, and their connections to Darboux-like properties. Beyond existence, I will outline results on the lineability and additivity of the family $\mathrm{SZ} \cap \mathrm{AC}$, and explain how different set-theoretic assumptions influence these algebraic structures.

This talk is based on a joint work with K. C. Ciesielski and T. Natkaniec [1]

1. K.C. Ciesielski, T. Natkaniec, T. and D. L. Rodríguez-Vidanes, *Almost continuous Sierpiński–Zygmund functions under different set-theoretical assumptions*, Rev. Real Acad. Cienc. Exactas Fis. Nat. Ser. A-Mat. 117, 19 (2023). https://doi.org/10.1007/s13398-022-01347-w

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Path integration on Riemannian manifolds

The field of infinite-dimensional integration theory is relevant due to its connections with Quantum Field Theory, where the celebrated path integral introduced by R. Feynman remains to this day a poorly understood mathematical object, yet essential for the development of experimental calculations carried out in particle colliders. As suggested by the *nLab* entry dedicated to the path integral,

> *Ours is the era whose central question in fundamental theoretical physics is:*
> *What is quantum field theory?*
> *A closely related question is: What is the path integral?*

In 1999, L. Andersson and B. K. Driver succeeded in reducing the computation of path integrals on Riemannian manifolds (with respect to Wiener measure) of bounded and continuous functionals to a limit of finite-dimensional integrals. These approximations closely resemble the informal formulas for path integrals used in physics that motivate Feynman's definition. My main contribution to this field [1] is to provide a new approximation scheme based on the categorical notion of colimit, which generalizes the one given by Andersson and Driver. In this talk, I will introduce the basic concepts necessary to understand this field of research and summarize the main results of Andersson–Driver and [1].

1. J.C. Sampedro, *Approximation Schemes for Path Integration on Riemannian Manifolds*, J. Math. Anal. Appl. **512**, Issue 2 (2022).

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Coherence of group pairs

A group is coherent if all its finitely generated subgroups are finitely presented. In 2023, Jaikin-Zapirain and Linton confirmed that one-relator groups are coherent by proving a criterion for coherence of groups of cohomological dimension two. In this talk I will explain how to generalize this criterion to group pairs of cohomological dimension two and show how it can be used to prove that one-relator products of coherent locally indicable groups (of arbitrary dimension) are coherent. This is joint work with Andrei Jaikin-Zapirain and Marco Linton.

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Number of lattice points in a ball

In a ball of large radius this number of points can be approximated by the volume of the ball; but, how precise is that approximation? In this talk I will tell the history of this problem as well as ideas to improve what is known about it.