Reunião do Conselho Científico do CIDMA Data: 10-jan-2023; Início: 14h30m; Local: Anfiteatro 11.1.10

CIDMA–Relatório de atividades de 2022 e Plano de atividades para 2023

O relatório de atividades de 2022 e plano de atividades para 2023 são apresentados seguindo a organização do CIDMA em grupos de investigação. Os grupos de investigação do CIDMA são:

a) Álgebra e Geometria (Responsável Científico: Dirk Hofmann);

b) Análise Complexa e Hipercomplexa (Responsável Científico: Uwe Kaehler);

c) Análise Funcional e Aplicações (Responsável Científico: Luís Filipe Castro);

d) Geometria e Dinâmica Gravitacionais (Responsável Científico: Carlos Herdeiro);

e) História da Matemática e Educação Matemática (Responsável Científico: Helmuth Malonek);

f) Otimização, Teoria de Grafos e Combinatória (Responsável Científico: Alexandre Plakhov);

g) Probabilidades e Estatística (Responsável Científico: Adelaide Freitas);

h) Sistemas e Controlo (Responsável Científico: Natália Martins).

O Coordenador Científico do CIDMA Delfim Fernando Marado Torres

Delfion F. M. Jones

Report 2022, Plans 2023

Algebra and Geometry Group

<2023-01-03 Tue>

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$1 \quad 2022$

1.1 Research topics

- Algebraic Combinatorics and Discrete Geometry,
- Combinatorial and geometrical properties of spherical tilings,
- Algebraic geometry and Number theory,
- Category theory and its applications to Algebra and Topology,
- Algebraization of logics,
- Coding theory and Cryptography,
- Interactive educational software,
- Computational Thinking.

1.2 Main achievements

- Existence of Pseudo-Hurwits maps on the alternating and symmetric groups.
- We obtained a classification of intersection family curves of an arbitrary ellipsoid with an arbitrary torus, sharing the same center, based on the number of their connected components and the number of their self-intersection points.

- We studied solutions of different Diophantine equations, and proved non-existence of solutions for the equations $x^2 + d * y^2 = z^p$ and $x^2 + d * y^6 = z^p$. Our expectation is that the techniques developed could be applied to other equations as well.
- We worked on the problem of bounding the 2-Selmer group of elliptic curves. We managed to extend our results to general hyperelliptic curves.
- We worked in the development of two cryptographic systems, the first being a convolutional variant of the McEliece cryptosystem and the second being a variant of the Niederreiter cryptosystem, in a generalization of the Euclid-Euler theorem for alfa-perfect numbers, on the study of divisors-free regions of certain integers, on the study of fractal regions related to the Aubry algorithm, and on the study of quantum convolutional codes.
- We studied and developed formalisms to describe scenarios where reactivity and reconfiguration are present, in particular, in the application of mathematical formalisms to the design and analysis of biological and pharmaceutical models.
- We introduce a language of first-order hybrid logic in which function symbols are interpreted by partial functions and prove a number of completeness results.
- We define a new fuzzy epistemic logic with public announcement with fuzzyness on both transitions and propositions. The core idea is that, the effect of a public announcement is reflected on the transitions degrees of the models. We prove the soundness of all axioms of the multi-agent epistemic logic with public announcements with respect to this graded semantics. We also introduce the notion of bisimulation and prove the modal invariance property for our logic.
- We propose a more general structure called Reversal Fuzzy Switch Graph (RFSG), which promotes other actions in addition to updating the fuzzy values of the arrows, like activation and deactivation of the arrows. We also provide a logic to verify properties of the modeled system.
- We generalised Belnap-Dunn four-valued logic, introducing paraconsistent transition systems (PTS), endowed with positive and negative accessibility relations, and a metric space over the lattice of truth values, and their modal logic. Paraconsistent transition systems, and their maps, are further explored. An algebra of structured operators specification for this logic is also characterised.
- We introduced a class of automata and associated languages, suitable to model a computational paradigm of fuzzy systems, in which both uncertainty and simultaneity are taken as first class citizens. This requires a weighted semantics for transitions and a precise notion of a synchronous product to enforce the simultaneous occurrence of actions. The usual relationships between automata and languages are revisited in this setting, including a specific Kleene theorem.
- A pretorsion theory for the category of all categories is presented. The associated prekernels and precokernels are calculated for every functor.
- It is shown that the reflection 2Cat → 2Preord of the category of all 2-categories into the category of 2-preorders determines a monotone-light factorization system on 2Cat and that the light morphisms are precisely the 2-functors faithful on 2-cells with respect to the vertical structure. In order to achieve such result it was also proved that the reflection 2Cat → 2Preord has stable units, a stronger condition than admissibility in categorical Galois theory, and that the 2-functors surjective both on horizontally and on vertically composable triples of 2-cells are the effective descent morphisms in 2Cat.

- We established a connection between certain modules over a quantale and cocomplete quantale-enriched multicategories, generalizing a previously known result for quantale-enriched categories.
- We developed duality theory for enriched Priestley spaces and enriched (distributive) lattices. We improve our previous work and show how certain duality results for categories of [0,1]-enriched Priestley spaces and [0,1]-enriched relations can be restricted to functions. In a broader context, we investigate the category of quantale-enriched Priestley spaces and continuous functors, with emphasis on those properties which identify the algebraic nature of the dual of this category.
- We determined, in coalgebraic and quantalic generality, when a functor lifting is induced by a class of predicate liftings or by a lax extension, and showed coincidence of the respective induced notions of behavioural distances, in a unified approach via double categories that applies even more widely, e.g. to (quasi)uniform spaces.
- We provide a quantitative coalgebraic Hennessy-Milner theorem that applies more widely to functors native to metric spaces; notably, we thus cover, for the first time, the well-known Hennessy-Milner theorem for continuous probabilistic transition systems, where transitions are given by Borel measures on metric spaces, as an instance.
- We analyzed the potential of introducing Computational Thinking as a skill to be developed in the mathematics curriculum through an activity that can be developed in the classroom regarding the Collatz Conjecture.

1.3 Conferences organization

Members of our group took part in the organization of the following events:

- Primeiro Encontro Português de Teoria dos Números, held at the University of Aveiro on the 2nd of November of 2022.
- Thematic Session: Mathematical Logic, Joint meeting Brasil-Portugal in Mathematics, Salvador, Bahia, August 18 19.
- DaLí 2022: Dynamic Logic: New Trends and Applications (online), July 31 Aug. 1, 2022.
- WADT'22 26th International Workshop on Algebraic Development Techniques, Aveiro-Portugal, June 28-30, 2022.
- NCL'22 NCL'22: NON-CLASSICAL LOGICS. THEORY AND APPLICATIONS 2022. Lodz, 14-18 March 2022.
- World Logic Day in Aveiro. Department of Mathematics, University of Aveiro, Jan 14, 2022 (Part of WORLD LOGIC DAY of UNESCO).
- Topology, Algebra, and Categories in Logic (TACL), University of Coimbra, June 20 24, 2022.

1.4 Conference presentations

- Domenico Catalano, "Which simple groups are automorphism groups of chiral maps (or not)". The Algebraic Graph Theory International Webinar, January 4, 2022.
- Manisha Jain, "Introducing fuzziness in quantum automata". WADT-22 26th International Workshop on Algebraic Development Techniques 2022, June, from 28 to 30th, 2022. Aveiro, Portugal.

- Antonio Breda d'Azevedo, "Orientability versus pseudo-orientability (un update)". SIGMAP 2022, Fairbanks (USA), Alaska, July 10-16.
- Ariel Pacetti, "Computing Paramodular forms using Quinary modular forms", Seminari de Teoria de Nombres de Barcelona 2022, University of Barcelona, between the 31st of January and the 4th of February 2022.
- Ariel Pacetti, "On 2-Selmer group of elliptic curves", Novenas Jornadas de Teoría de Números, Universidad de La Rioja, between the 28th of June and the 1st of July 2022.
- Ariel Pacetti, "Bounds for the 2-Selmer group of elliptic curves", Primeiro Encontro Português de Teoria dos Números, University of Aveiro, 2nd of November of 2022.
- João Xarez, "The Monotone-Light Factorization for 2-categories via 2-preorders" in the international conference "Topology, Algebra, and Categories in Logic (TACL 2022), Coimbra, 20-24 June 2022.
- Paulo Almeida, "Divisors of N, close to the square root of N" Primeiro Encontro Português de Teoria dos Números, November, the 2nd, 2022. University of Aveiro, Portugal.
- Paulo Almeida, "Smaller Keys for the McEliece Cryptosystem: A convolutional variant with GRS codes". Coding theory and Cryptography, a conference in honor of Joachim Rosenthal's 60th birthday, July, from 10 to 15th, 2022. University of Zurich, Switzerland.
- Paulo Almeida, "Optimal quantum convolutional codes". WADT-22 26th International Workshop on Algebraic Development Techniques 2022, June, from 28 to 30th, 2022. Aveiro, Portugal.
- Paulo Almeida, "Laurent matrices for a convolutional variant of the McEliece cryptosystem". 9th International Conference on Matrix Analysis and Applications (ICMAA 2022), June, from 15 to 17th, 2022. University of Aveiro, Portugal.
- Figueiredo, D., Jaime, Santos. idDL2DL: translating interval specifications to DL. Presentation in 26th International Workshop on Algebraic Development Techniques 2022 (WADT'22).
- D. Costa, D. Figueiredo. Equational logic over switch graph models. Presentation in 26th International Workshop on Algebraic Development Techniques 2022 (WADT'22).
- Santos, J., Figueiredo, D., Madeira, A. Tool support for interval specifications in differential dynamic logic. Presentation in 17th International Workshop on Logical and Semantic Frameworks, with Applications (LSFA).
- Alexandre Madeira, "Towards the generation of graded modal logics: parametric methods and applications". Encontro Conjunto Brasil Portugal em Matemática, sessão Lógica Matemática.
- Dirk Hofmann, "From compact metric spaces to metric compact spaces". Encontro Nacional da SPM 2022. Tomar, Portugal, July 18–20, 2022.
- Dirk Hofmann, "On the double category of coalgebras". TACL 2022 Topology, Algebra, and Categories in Logic. Coimbra, Portugal, June 20–24, 2022.
- Dirk Hofmann, "Extensions and liftings of functors". 5th Workshop on Categorical Algebra: recent developments and future perspectives. Gargnano del Garda, Italy, April 26–30, 2022.
- Dirk Hofmann, "On the double category of coalgebras". XIII Portuguese Category Seminar. Coimbra, Portugal, February 25, 2022.

- Dirk Hofmann, "Topology through the eyes of enriched categories". Categories and Companions Symposium. online, September 19–23, 2022.
- Dirk Hofmann, intensive course on "Duality theory", TACL 2022 Summer School. Praia de Mira, Portugal, June 13–18, 2022.
- Freire, Alfredo Roque. "On many logic modal logic systems", Logic day Aveiro. Aveiro, Portugal, January 14, 2022.
- Freire, Alfredo Roque. "Modality in worlds with different logics", TACL 2022 Topology, Algebra, and Categories in Logic. Coimbra, Portugal, June 20–24, 2022.
- Freire, Alfredo Roque. "Partial boolean valued model and exact forcing", WADT 22 26th International Workshop on Algebraic Development Techniques 2022. Aveiro, Portugal, June 28 - 30 2022.
- Freire, Alfredo Roque. "Modality in worlds with different logics", Encontro Brasil Portugal de Matemática. Salvador, Brazil, August 14 20, 2022.
- Trocado, A., Dos Santos, J., Lavicza, Z., "Develop Computational Thinking in Portuguese Mathematics Curricula with Collatz Conjecture", ATCM 2022 - Asian Technology Conference in Mathematics, Prague, December, 2022.
- Breda, A., Trocado, A., Dos Santos, J., "The intersection curve of an ellipsoid with a Torus sharing the same center", ICGG 2022 International Conference on Geometry and Graphics, Online, August, 2022.

1.5 Seminars

- Ariel Pacetti, "Zeta function of projective varieties", CMUP seminar, University of Porto, 14th of December of 2022.
- Paulo Almeida, "Quantum Error Correcting Codes", Grupo de Álgebra e Geometria, June the 10th, 2022. University of Alicante, Spain.
- Paulo Almeida, "Pre and post quantum cryptography". Workshop A first contact with quantum computing, September the 28th, 2022. University of Aveiro, Portugal.
- Paulo Almeida, "Millenium Problems", by invitation of NEMat, when the firm Gifted was exhibited, March the 23th, 2022. University of Aveiro, Portugal.
- Paulo Almeida, "How to prevent the quantum apocalypse". Jornadas de Matemática em Ciências, 12 de março de 2022, Faculdade de Ciências da Universidade de Lisboa, Portugal.
- Freire, Alfredo Roque. "Introduction to constructibles", University of São Paulo, 3 encontros. São Paulo, Brazil, February 14- 25, 2022.
- Freire, Alfredo Roque. "Translations of theories and the collapsing of pre and partial orders", Logic Seminar University of São Paulo. São Paulo, Brazil, April 24, 2022.
- Freire, Alfredo Roque. "O fenômeno de Tightness nas teorias de classes", Seminar Computability, Approximate Reasoning, Ordered structures and Logics. Natal, Brazil, December 7, 2022.

1.6 Visitors

- Víctor Aranda, Department of Logic and Theoretical Philosophy, Complutense University of Madrid (May 30 to July 3).
- Mário Benevides (Universidade Fulminense, Brasil)
- Rolf Hennicker (LMU, Germany)
- Alexander Knapp (U. Augsburg, Germany)
- Eli Hazel, Macquarie University, Australia

2 2023

2.1 Topics

- Many lattice based modal systems
- Reversal fuzzy switch graphs: adding aggregation-based operations
- Partial Propositional Type Theory
- Relation-changing models with paraconsistency
- Informative gluing and collapsing of pre-orders
- (Weak) quantitative bisimulations
- nuclear enriched lattices
- Monotone-light factorization for n-categories
- Study of modal logic in reactive and reconfigurable contexts.
- Classification of intersection family curves of a quadric with an arbitrary torus.
- Study of the chirality and reflexibility of the pseudo-Hurwits maps on Sn and An.
- Complete classification on pseudo-oreintable regular maps having as automorphism group alternating or symmetric group.
- Achieve new results on finite left Bol loops and finite gyro-groups.
- Computational Thinking.

2.2 Conference organization

Members of our group will take part in the organization of the following events:

- TQC 2023 (Theory of Quantum Computation, Communication and Cryptography) in the University of Aveiro, from July 24th until July 28th, 2023.
- Summer School on Quantum Information in the University of Aveiro, from July 17th until July 21th, 2023, local chair.
- Theory of Quantum Computation, Communication and Cryptography, Aveiro, 24-28 July, 2023.
- Session on "Enriched Categories and Topology" of the 36th Summer Conference on Topology and Its Applications em Youngstown, Ohio, July 17 21, 2023.

2.3 Conferences and seminars

- SAGA (Symposium on Arithmetic Geometry and its Applications Symposium sur la géométrie arithmétique et ses applications) 6 10 February 2023, CIRM, 163 avenue de Luminy, Case 916 13288 Marseille cedex 9, FRANCE
- FoCM 2023, Foundations of Computational Mathematics, 12-21 June 2023, Paris France
- Workshop about Coding Theory with work groups that will try to make progress on some of the topics discussed. June, from 5 to 9th, 2023.
- V International Congress on Tools for Teaching Logic: Madrid, March 23-24, 2023
- Wollic 2023.
- SPLogic 2023.
- Logic Seminar University of Paris VII (invited).
- Category Theory 2023, UC Louvain, Louvain-la-Neuve, Belgium.

2.4 Visits

- University of Alicante, Spain.
- Department of Logic and Theoretical Philosophy, Complutense University of Madrid, Spain.
- York University, Toronto, Canada
- University of Western Cap, South Africa

2.5 Visitors

- João Marcos, Department of Informatics and Applied Mathematics (DIMAp), UFRN, Brasil.
- Patrick Blackburn, from University of Roskilde, Denmark.
- Marco Abbadini, University of Salerno, Italy.
- Pedro Nora, University Nuernberg-Erlangen, Germany.

Report on the activities of GACH for the year 2022

Research topics and principal results:

Continuing our work on spectral theory for quaternionic and Clifford-valued operators we established a version of the Grothendieck-Lidskii formula for the eigenvalues of quaternionic nuclear operators over locally convex spaces. This required the establishment of an appropriate definition of traces and Fredholm determinants for quaternionic operators.

The group also continued to work in the field of fractional derivatives, including their spectral theory. Hereby, the experience of the group in the field of special functions was used to investigate eigenfunctions of fractional derivatives and its applications to boundary value problems as well as Cauchy problems were studied. Furthermore, based on the previous work on harmonic analysis over hyperbolic spaces we are constructing fractional differential operators using the s-resolvent of Dirac operators over hyperbolic manifolds. Additionally, Strichartz and dispersive estimates have been obtained in the case of fractional damping equations with memory.

Continuing its work on harmonic analysis the group worked on Fourier inequalities in Morrey spaces and Fourier transforms of general monotone functions and two-sided Hardy-Littlewood inequalities. Fourier transforms and Fourier-like transforms like the linear canonical transform were also studied over hyperbolic spaces as well as the corresponding Gabor transforms.

In our work on analysis over discrete structures we started to build a white and grey noise analysis using q-Jackson derivatives and the q-Mellin transform. Hereby, we also constructed the appropriate spaces of stochastic distributions and test functions. The application of this theory to stochastic processes has been started. Additionally, the connection between discrete and continuous Dirac equations and integro-differential equations is being studied.

In the topic of magnetohydrodynamic equations (MHD equations) we successfully combined function-theoretical methods with variational methods to prove existence and uniqueness. The employed method can be used to study a variety of different equations and greatly enlarges the scope of applicability of methods from hypercomplex analysis. Additionally, combinatorial identities arising from hypercomplex functions are being studied.

Furthermore, matricial orthogonal polynomial are being studied as well as Markov chains and multiple orthogonality. The group is also continuing its work on higher-dimensional orthogonal polynomials with applications in integrable systems.

In the field of mathematical education, we continued our work inside the project PARFORCE which aims to create access to laboratories using VR sets and virtual environments.

The group also worked on the development of new activation functions for artificial neural networks and its applications in structural health monitoring (SHM). Special attentions were

given to the case of Bessel functions with its importance for practical applications. Results clearly show Bessel activation functions outperform (especially in terms of rapidness) classic activation functions such as the *ReLU* activation function

Research visits:

During the year members of the group have visited several research centers. Among them is a long term stay of Uwe Kaehler at the Politecnico di Milano, a visit of Nelson Vieira to Tampere University of Technology and a visit of A. Debernardi at the Centre de Recerca Matemàtica in Barcelona.

Additional activities:

The project Hypergeometric Functions and Machine Learning in the Diagnosis Process coordinated by Nelson Vieira in Advanced Computing was selected by FCT and Google for funding in the value of 81 089 USD.

Paula Cerejeiras a member of evaluation panel M1- Mathematics at the Science Foundation of Flanders (FWO-Belgium) was responsible for the distribution of PhD and Post-Doc grants of the Science Foundation

Ana Foulquie was invited as evaluator for the assessment of proposals in the call HORIZON-MSCA-PF- 2022 whiled Uwe Kaehler worked as evaluator for project applications in Mathematics at the Czech Science Foundation 2022.

Uwe Kaehler also continued his work as president of the International Society of Analysis, its Applications, and Computation (ISAAC) during the year.

Publications:

The group published 10 papers in international journals like Mathematische Annalen and Journal of the EMS. 4 papers were published as book chapters and conference proceedings.

Communications:

The group gave more than 20 presentations in international conferences. In particular, the invited communication of P. Cerejeiras at the International Conference: Multidisciplinary Aspects in Mathematics and its Applications (ICMAM 2022) deserves being singled out given that she was one of the 19 invited speakers of this conference including Terence Tao, UCLA, USA, Michael Ruzhansky, Ghent University and Queen Mary University of London, Belgium and UK, Tatiana Toro, Department of Mathematics, University of Washington, USA, Simon Donaldson, Imperial College London, UK, and Carlos Kenig, University of Chicago.

Collaborations:

The group is continuing its wide range of international collaborations. Among them we can single out collaborations with the Institute of Digital and Autonomous Construction at Technical University Hamburg, the research group of hypercomplex analysis at Politecnico di Milano, the Center for Excellence in hypercomplex analysis at Chapman University, the corresponding research groups at University of Erfurt, TU Bergakademie Freiberg, and Tampere University, as well as the research group in orthogonal polynomials at the University of Granada. Close collaboration also exists with the Ghent Analysis and PDE center and the Institute of Analysis, Dynamics and Modeling at University of Stuttgart.

Participation in projects:

Group members coordinated and participated in the following projects:

- ERASMUS+ Strategic Partnership Partnership for virtual laboratories in civil engineering PARFORCE, 2020-1-DE01-KA226-HE-005783, 2021 2023.
- Hypergeometric Functions and Machine Learning in the Diagnosis Process, FCT and Google, 2022-2023.
- Ortogonalidad y aproximación con aplicaciones en machine learning y teoría de la probabilidad, PID2021-122154NB- 100, Ministerio de Ciencia, Innovación y Universidades (MICINN), Espanha, 2022-24.
- Fault-tolerant wireless structural health monitoring based on frame analysis and deep learning Deutsche Forschungsgemeinschaft (DFG), LE 3955/4-1, 2018-2022
- Perspectivas Teóricas y Prácticas de la Ortogonalidad A-FQM-246-UGR20. Projectos de I+D+I for research teams in the framework of FEDER, 2021-2023.
- Approximation of nonlinear signals by atoms of Blaschke product type and its application in hyperspectra data Natural Science Foundation of China (NSFC), n.o 11971178, 2020-2023
- Polinomios Ortogonales Multivariados. Aspectos Teóricos y Aplicaciones Científicas, PGC2018-094932-B-I00. Research projects subsidised by Ministerio de Ciencia, Innovación y Universidades (MICINN) and FEDER. 2019 2022.

Conference organization:

Members of the group organized or were involved in the organization of the following conferences:

- 24th European Intensive Course on Complex Analysis, its Generalizations and Applications, University of Aveiro, Portugal, 2/03-01/04/2022.
- 20th Annual Workshop on Applications and Generalizations of Complex Analysis, University of Aveiro, Portugal, 25-26/03/, 2022.
- Symposium Fractional differential theory and applications, International Conference on Mathematical Analysis and Applications in Science and Engineering ICMA²SC'22, Polytechnic of Porto. School of Engineering, Portugal, 27-29/06/2022.

- German-Portuguese Workshop on fault-tolerant wireless structural health monitoring, 30/06-01/07/2022, University of Aveiro, Portugal
- Symposium *Fractional Differential Calculus and Clifford Analysis*, International Conference of Numerical Analysis and Applied Mathematics ICNAAM 2022, Crete, Greece, 19-25/09/2022.
- Sixth Workshop New Trends in Quaternions and Octonions (NTQO 2022), Universidade da Beira Interior, Covilhã, Portugal, 25-26/11/2022.

Research plan for 2023

Research topics:

Additionally to continuing our work on the topics from the previous year we are going to work on the following topics:

- Spectral theory over noncommutative structures by studying the case of Cliffordvalued nuclear operators.
- Study of the fractional Helmholtz operator and development of the correspondent operator theory in the Clifford analysis setting.
- Study of the fractional gradient defined in terms of ψ-Hilfer fractional derivatives and development of a numerical method to solve optimization problems.
- Investigation of time and/or space fractional differential equations with general fractional derivatives.
- Study of Lie symmetries of different operators in the context of Clifford analysis
- Boundedness of Hausdorff operators on general weighted Morrey-type spaces
- Construction of pseudodifferential operator calculus in different settings
- Application of Bessel activation functions in civil engineering problems, namely in fault detection and classification problems.

Conference organization:

- European Intensive Course on Complex Analysis, its Generalizations and Applications, University of Aveiro, March 27-April 1, http://sweet.ua.pt/pceres/Complex2023/Webpage/ElCourse.html
- Annual Workshop on Applications and Generalizations of Complex Analysis in Aveiro, March 24-25, http://sweet.ua.pt/pceres/Complex2023/Webpage/Workshop.html
- International Conference on Mathematical Methods in Physics, Marrakesh, Morocco, April, 24 28, https://icmmp23.com/
- Workshop New Trends in Quaternions and Octonions in Polytechnic of Leiria.

Conference participation:

Members of the group received invitations to present talks at the following conferences:

 13th International Conference on Clifford Algebras and Their Applications in Mathematical Physics, Holon Institute of Technology (Israel), June 4-9, 2023. https://sites.google.com/view/icca13-holon/home Conference on Orthogonal Polynomials and Applications in honor of the 65th birthday of W. van Assche, University of Leuven (KU Leuven), Belgium, June 8-10, 2023

International Collaboration:

We plan to continue our existing international collaborations.

Master/PhD theses:

The finalization of 4 Master theses and one PhD thesis is predicted for 2023.

CIDMA

2022 Functional Analysis and Applications Group (GAFA) Activities Report

Members (with PhD):

António Manuel Rosa Pereira **Caetano (group leader from January 1st to October 23rd)** Anabela de Sousa e **Silva** Eugénio Alexandre Miguel **Rocha** Helena Daniela Ferreira **Gonçalves** José Alexandre Rocha **Almeida** Kelly **Murillo** Luís Filipe Pinheiro de **Castro (group leader since October 24)** Maria Manuela Fernandes **Rodrigues** Vasile **Staicu**

Member without PhD (PhD Student):

Joana Dirce Santos Martins

Collaborators:

Ana Paula Branco Nolasco (Universidade de Aveiro) Alberto Manuel Tavares Simões (CMA – Centro de Matemática e Aplicações, UBI) Rita Catarina Correia Guerra (CMUC – Centro de Matemática, Universidade de Coimbra) Sandrina Rafaela Andrade Santos (Universidade de Aveiro)

We studied properties of general integral transforms (that is, some that encompass other more particular and well-known integral transforms). This was the case of the offset linear canonical transform for which several new properties were discovered. The offset linear canonical transform, being an integral transform depending on six parameters, includes, as particular cases, some of the most widely used integral transforms. In fact, the offset linear canonical transform is a generalization of e.g. the Fourier transform, the fractional Fourier transform, the linear canonical transform, the Fresnel transform and the Gauss-Weierstrass transform. Besides this great generality, the offset linear canonical transform has also shown to be a very powerful tool in several applied areas (as it is the case of signal processing and optics). We have introduced a new correlation associated with the offset linear canonical transform which presents a significant simplicity in both time and offset linear canonical transform domains. Using the new correlation, we were able to design multiplicative filters in the offset linear canonical transform domain as well as to establish a sampling theorem for band-limited signals. A remarkable issue in the new correlation is its simplicity in the sense that it can be seen as the classical convolution of two functions. Some special cases of our new correlation (e.g. with properties directly associated with the fractional Fourier transform

and the Fourier transform) were also introduced. We have also proposed different ways to design filters. For instance, the multiplicative filter in the offset linear canonical transform domain have been analysed. We concluded that the multiplicative filter through convolution in the time domain can be realized by the fractional Fourier transform and has the same capability, but less computational complexity when compared with the method achieved in the offset linear canonical transform domain. The sampling of band-limited signals in the offset linear canonical transform domain has been further investigated. In particular, we have obtained formulas of uniform sampling and low-pass reconstruction.

We studied the solvability of some classes of integral operators and corresponding integral equations. In particular, a class of integral operators whose kernel depends on four different functions was studied. Necessary and sufficient conditions for the unique solvability of such integral equations were obtained. To achieve this goal, the main technique consisted in introducing eight new convolutions weighted by multidimensional Hermite functions and using them as convolutions somehow associated with our integral equations. Along the way, Young-type inequalities were also obtained. Thus, the construction of new convolutions was also crucial to increase the knowledge of integral equations and operators, namely by obtaining conditions that allow deducing the solvability of a very general class of integral equations.

Problems of fractional differential equations with initial/boundary conditions were studied, e.g. involving fractional Caputo and Riemann-Liouville derivatives, obtaining sufficient conditions for the existence and uniqueness of solutions as well as for their stability (of Ulam-Hyers and Ulam-Hyers-Rassias types). The main used techniques included fixed point arguments (for example, the Krasnoselskii's Fixed Point Theorem) Functional Analysis and Operator Theory methods, and differential and integral inequalities.

We have considered the non-homogeneous time fractional diffusion and telegraph equations with fractional derivatives in the ψ -Hilfer sense, subject to initial and boundary conditions. For both equations it was obtained an explicit integral and representations of the solutions of the Cauchy problem associated to these equations. Moreover, it was proved in which conditions the correspondent fundamental solutions can be interpreted as a spatial probability density function evolving in time. In the case of the time-fractional telegraph equation our results generalize the correspondent ones obtained by of Orsingher and Beghin (in 2004).

Within the time-fractional telegraph equation of distributed order in higher spatial dimensions, where the time derivative is in the sense of Hilfer, it was obtained a representation of the solution of the Cauchy problem associated with the equation in terms of convolutions involving functions that are Laplace integrals of Fox H-functions. Fractional moments of the first fundamental solution are computed and for the special case of double-order distributed it is analysed in detail the asymptotic behaviour of the second-order moment, by application of the Tauberian Theorem.

For the fractional relaxation-oscillation equation with a force term, where the time-fractional derivatives are in the ψ -Hilfer sense it was obtained a solution for this equation in terms of

bivariate Mittag-Leffler functions. An asymptotic analysis of the solution of the associated homogeneous equation was performed.

It was studied the eigenfunctions of the time-fractional wave operator with the time-fractional derivative in the Caputo sense, and we have obtained representations for the eigenfunctions of the time-fractional wave operator with the time-fractional derivative in the Caputo sense.

We studied the main properties of the eigenfunctions and the eigenvalues of the associated fractional boundary problem of the ψ -fractional Sturm-Liouville eigenvalue problem by using left ψ -Caputo and right ψ -Riemann-Liouville fractional derivatives.

We have investigated the so called Stummel spaces with variable exponents (jointly with H. Rafeiro from United Arab Emirates University, Al Ain, UAE). The boundedness of the Hardy-Littlewood maximal operator on such spaces was established (result already published) as a first crucial step in this direction. The research in these spaces continues to be carried out in order to understand the behavior of other classical operators in this setting (e.g., fractional integral operators, singular operators, etc.). We have also studied (jointly with S. Samko from University of Algarve) the inversion of the Riesz potential operator in a general framework, aiming to extend and unify related results existing in the literature on different function spaces. We have also produced (jointly with H. Rafeiro and Z. Kusraeva) a review paper dedicated to Professor Stefan Samko on the occasion of his 80th birthday, on his research activity in the last decade.

Other properties of some function spaces were also analysed, all being part of the large scale of *smoothness Morrey spaces*. More precisely, Besov-type spaces and Triebel-Lizorkin-type spaces were considered, not only with constant exponents, but also the 2-microlocal version with variable exponents.

It was concluded the paper "A Hausdorff-measure boundary element method for acoustic scattering by fractal screens" (with S. Chandler-Wilde, A. Gibbs, D. Hewett, A. Moiola) which is now going to be submitted for publication in an international journal. It deals with the scattering of acoustic waves by sound-soft fractal screens, with a novel application of the boundary element method (BEM) where each BEM basis function is supported in a fractal set, and the integration involved in the formation of the BEM matrix is with respect to a non-integer order Hausdorff measure. In this way, for a class of fractals that are attractors of iterated function systems, convergence rates for the BEM can be proved under certain natural regularity assumptions on the solution of the underlying boundary integral equation.

We studied the existence and properties of solutions to initial-boundary value problems for some quasilinear parabolic equations with the nonmonotone multivalued terms. We firstly setup a framework which enables us to treat existence of strong solutions of a wider range of nonlinearity of the multivalued term G(t,x,u) to cover the growth condition with respect to u up to the Sobolev subcritical range and secondly adapt and improve the techniques and arguments developed in two our previous papers in order to obtain existence results for the parabolic inclusion generalizing corresponding results given by many authors. The advantage of our treatment lies in the fact that to show the existence of time-local strong solutions of

the considered problem, it allows the Sobolev-subcritical growth order of G(t,x,u) with respect to u, which has been left as an open problem even for the case where G(t,x,u) is a singlevalued function.

We considered an anisotropic Neumann problem with an indefinite potential term and a reaction which is only locally defined and odd. Using a variant of the symmetric mountain pass theorem, we showed that the problem has a whole sequence of smooth nodal solutions which converge to zero in C^1 functions space.

We considered a nonlinear logistic equation of superdiffusive type driven by a nonhomogeneous differential operator and a Robin boundary condition. We prove a multiplicity result for positive solutions which is global with respect to a parameter $\lambda > 0$ (bifurcation-type theorem). We also demonstrate the existence of a minimal positive solution and determine the monotonicity and continuity properties of the minimal solution with respect to the parameter.

We continued the study of quasilinear elliptic systems in divergence form. In general, we cannot expect that weak solutions are locally bounded because of De Giorgi's counterexample. By assuming that off-diagonal coefficients have a "butterfly support" we proved the local boundedness of weak solutions.

<u>Applications to the Industry 4.0</u>: A GAFA member coordinates industrial projects where mathematics, machine learning and big data analytics are used in the context of Industry 4.0, by developing innovative techniques/approaches for solving real problems in topics as:

- [AI01] Impact analysis of KPI scenarios, automated best practices identification, and deviations on manufacturing processes (E. Rocha, M. J. Lopes¹);
- [AI02] Benchmarking and prediction of entities performance on manufacturing processes through MEA, robust XGBoost and SHAP analysis (E. Rocha, A. Brochado¹, B. Rato¹, J. Meneses²);
- [AI03] Bottleneck prediction and data-driven discrete-event simulation for a balanced manufacturing line (E. Rocha, M .J. Lopes¹);
- [AI04] Predictive maintenance on sensorized stamping presses by time series segmentation, anomaly detection, and classification algorithms (D. Coelho¹, D. Costa¹, E. Rocha, J. Santos);
- [AI05] Workers benchmarking using multi-directional efficiency analysis in a manufacturing production system (E. Rocha, A. Brochado¹, A. Moura);
- [AI06] Real-time condition-based maintenance of friction welding tools by generalized fault trees (P. Nunes¹, E. Rocha, J. Neves², J. Santos);
- [AI07] Minimizing false-rejection rates in gas leak testing using an ensemble multiclass classifier for unbalanced data (D. Costa¹, E. Rocha, P. Ramalho²);

¹ PhD student (co)supervised by E.Rocha

² Company collaborator where the use case was studied

- [AI08] Application of deep learning approach for the classification of buildings' degradation state in a BIM methodology (F. Rodrigues, V. Cotello, H. Rodrigues, E. Rocha, F. Freitas, R. Matos);
- [AI09] A data-driven model with minimal information for bottleneck detection application at Bosch thermotechnology (A. Brochado¹, E. Rocha, D. Almeida², A. Sousa, A. Moura);
- [AI11] Understanding and Predicting Process Performance Variations of a Balanced Manufacturing Line at Bosch (A. Brochado¹, E. Rocha, C. Pimentel);
- [AI12] PDCA Protocol to ensure a data-driven approach for problem-solving (A. Brochado¹, E. Rocha, C. Pimentel);
- [AI13] Reliability analysis of sensorized stamping presses by generalized fault trees (E. Rocha, P. Nunes¹, J. Santos);
- [AI14] Predictive maintenance on injection molds by generalized fault trees and anomaly detection (P. Nunes¹, E. Rocha, R. Antunes², J. Santos).

[AI01]-[AI11] are published, [AI12]-[AI14] are accepted for publication, and [AI14] received the best paper award (see <u>https://www.ua.pt/en/noticias/9/78317</u>). The results discussed have corresponding computational frameworks developed where some are already deployed (or are now at a deployment phase) to the shopfloor of industrial companies as Aleluia Cerâmicas, Bosch Security Systems, Bosch ThermoTechnology, Grupo Simoldes, Oliveira e Irmãos, Primus Vitoria, or Vista Alegre. The scientific results were discussed in four international conferences.

Applications to Econometrics: For a coherent study of data analysis, complete dynamic models, differentiated intermediation technologies and adequate choices are needed that do not affect the ability to reach the optimal benchmark, allowing a study of decision units adjusted to reality. In this sense, in 2022, it has deepened the study and search for a structure of dynamic efficiency, increasingly in line with real applications on the different contexts addressed. This has led to the proposal of a new multidirectional efficiency model in a dynamic version, and to carry out a comparative study between existing dynamic models and our proposal. As a result of the research work carried out this in this topic, five articles have been written in the following (sub)topics:

- [AE01] About the quality and sustainable education in European countries: a comparative econometric analysis (K. Murillo, E. Rocha);
- [AE02] Joint efficiency analysis of the circularity of the glass, paper and plastic waste economies for the European countries (K. Murillo, E. Rocha, M. Robaina, J. Villar);
- > [AE03] A dynamical multidirectional efficiency analysis (K. Murillo, E. Rocha);
- > [AE04] Implementing effective metrics in data analysis (K. Murillo);
- [AE05] Economic impact of the COVID-19 pandemic on production industry: a nonparametric comparative analysis (K. Murillo).

The results obtained have been disclosed in four international conferences and one national conference.

Outreach Activities:

- Members of GAFA collaborated in the outputs of some Thematic Lines, e.g. E. Rocha is the coordinator of the Thematic Line "*da Teoria às Ferramentas Computacionais*" (TFC) and he has been the co-coordinator of the Thematic Line "Geometrix", whereas the associated results are listed in the corresponding reports.
- E. Rocha supervised 5 PhD students (1 concluded in 2022) and 7 MSc students that concluded in 2022. M.J. Lopes was the first student to finish the PhD "Doctorate in Business Innovation", where she kept being an engineer at Bosch TT.
- E. Rocha is the director of the master in Mathematics and Applications, co-director of the master in Data Science and director of the specialized program Automation Intelligence, where the latest two are collaborations with the Computer Science Department and the Mechanical Engineering Department.
- A. Caetano is Vice-President of CIM (Centro Internacional de Matemática), with a special increase in involvement in the activities of this Centre due to health restrictions of the President.
- A. Caetano was elected in 2022, and for a 4-year mandate, as one of the four delegates representing the 48 institutional members of the EMS in its Council.
- A. Caetano started in November to supervise pro bono one of the grantees from the program Novos Talentos, in Mathematics, from the Calouste Gulbenkian Foundation.
- In 2022 L.P. Castro joined the pool of experts of the Institutional Evaluation Programme (IEP) of the European University Association. The mission of the Institutional Evaluation Programme (IEP) is to support higher education institutions and systems in developing their strategic leadership and capacity to manage change through a process of voluntary institutional evaluations.
- L.P. Castro was the invited external member to the annual meeting of the group of *Analysis and Applications* of the Centre of Mathematics (CMAT) – a research center of the University of Minho (UM), with a pole at the University of Trás-os-Montes and Alto Douro (UTAD). Among other components, in a full day participation, L.P. Castro gave the 1h30 Invited Talk: "Research groups: from structure to people... and vice versa", November 2022.
- V. Staicu is the Interim Vice-President of the American Romanian Academy of Arts and Sciences (ARA) (http://main.ara-as.org), Member of the Board of Directors of ARA in charge with the publications of ARA and Editor in Chief of the mathematical journal Libertas Mathematica (new series) edited in Aveiro with partial support from CIDMA under the auspices of ARA (http://system.lm-ns.org/index.php/).
- V. Staicu is the Local Coordinator at the University of Aveiro of the consortium RealMaths Mathematics for Real World Applications, a set of 2-year Double MSc programmes with focus on scientific computing and applications. Students spend one year at the University of L'Aquila and one year in one of the partner institutions.
- V. Staicu is a member of the Register of Expert Peer Reviewers for Italian Scientific Evaluation (REPRISE database) (<u>https://reprise.cineca.it/</u>) of the Ministry of University and Research (MIUR) of Italy, updated the in the section "Fundamental research" following the new European Research Council 2021 panel structure.

2022 Published Papers

- S. Aizicovici, N. S. Papageorgiou, **V. Staicu**, Infinitely many nodal solutions for anisotropic (p,q)-equations, Pure Appl. Funct. Anal. 7 (2022), no. 2, 473–486. http://hdl.handle.net/10773/35310.
- S. Aizicovici, N. S. Papageorgiou, **V. Staicu**, Nonlinear nonhomogeneous logistic equations of superdiffusive type, Appl. Set-Valued Anal. Optim. 4 (2022), 277-292. https://doi.org/10.23952/asvao.4.2022.3.03
- A. Almeida, H. Rafeiro, Maximal operator in variable Stummel spaces, J. Fourier Anal. Appl. 28, 50 (2022). <u>https://doi.org/10.1007/s00041-022-09940-8</u>
- A. Almeida, Z. A. Kusraeva, H. Rafeiro, PROFESSOR STEFAN G. SAMKO RESEARCH: A DECADE RETROSPECTIVE. J. Math. Sci. (2022). <u>https://doi.org/10.1007/s10958-022-05990-x</u>
- L. P. Castro, R.C. Guerra, N.M. Tuan, Convolutions and integral equations weighted by multi-dimensional Hermite functions, Asian-European Journal of Mathematics, Vol. 15, No. 8 (2022) 2250151 (35 pages), World Scientific Publishing Company, DOI: 10.1142/S1793557122501510
- Luís. P. Castro, Anabela S. Silva, On the solution and Ulam-Hyers-Rassias stability of a Caputo fractional boundary value problem, Mathematical Biosciences and Engineering 2022, Volume 19, Issue 11: 10809-10825. doi: 10.3934/mbe.2022505
- L. P. Castro, A. S. Silva, Ulam-Hyers stability of four-point boundary value problem of Caputo fractional differential equations with a parameter, Vladikavkaz Mathematical Journal, 2022, Volume 24, Issue 4, 77-90.
- L. P. Castro, L. T. Minh, N. M. Tuan, Filter design based on the fractional Fourier transform associated with new convolutions and correlations. Math Sci (2022). <u>https://doi.org/10.1007/s40096-022-00462-4</u>
- E. Rocha, M. J. Lopes, Impact analysis of KPI scenarios, automated best practices identification, and deviations on manufacturing processes, IEEE 27th International Conference on Emerging Technologies and Factory Automation (ETFA), 2022, pp. 1-6.
- E. Rocha, A. Brochado, B. Rato, J. Meneses, Benchmarking and prediction of entities performance on manufacturing processes through MEA, robust XGBoost and SHAP analysis, IEEE 27th International Conference on Emerging Technologies and Factory Automation (ETFA), 2022, pp. 1-8.
- F. Rodrigues, V. Cotello, H. Rodrigues, **E. Rocha**, F. Freitas, R. Matos, Application of deep learning approach for the classification of buildings' degradation state in a BIM methodology, Appl. Sci. 2022, 12:7403, 1-18.
- A. Brochado, **E. Rocha**, D. Almeida, A. Sousa, A. Moura, A data-driven model with minimal information for bottleneck detection application at Bosch thermotechnology, International Journal of Management Science and Engineering Management, 2022, 1-14.
- E. Rocha, M. J. Lopes, Bottleneck prediction and data-driven discrete-event simulation for a balanced manufacturing line, Procedia Computer Science 200, 2022, 1145-1154.

- D. Coelho, D. Costa, **E. Rocha**, J. Santos, Predictive maintenance on sensorized stamping presses by time series segmentation, anomaly detection, and classification algorithms, Procedia Computer Science 200, 2022, 1184-1193.
- E. Rocha, A. Brochado, A. Moura, Workers benchmarking using multi-directional efficiency analysis in a manufacturing production system, Procedia Computer Science 200, 2022, 1451-1460.
- P. Nunes, E. Rocha, J. Neves, J. Santos, Real-time condition-based maintenance of friction welding tools by generalized fault trees, In: Guarda, T., Portela, F., Augusto, M.F. (eds), Communications in Computer and Information Science 1675, Springer, 2022.
- D. Costa, **E. Rocha**, P. Ramalho, Minimizing false-rejection rates in gas leak testing using an ensemble multiclass classifier for unbalanced data, In: Guarda, T., Portela, F., Augusto, M.F. (eds), Communications in Computer and Information Science 1675, Springer, 2022.
- A. Brochado¹, **E. Rocha**, C. Pimentel, Understanding and predicting process performance variations of a balanced manufacturing line at Bosch, In: Guarda, T., Portela, F., Augusto, M.F. (eds), Communications in Computer and Information Science 1675, Springer, 2022.
- K. Murillo, E. Rocha, About the quality and sustainable education in European countries: a comparative econometric analysis, EDULEARN22 Proceedings, 187-4196.
- N. Vieira, **M. M. Rodrigues**, and M. Ferreira, *Time-fractional telegraph equation of distributed order in higher dimensions with Hilfer fractional derivative*, Electronic Research Archive, **30**-No.10 (2022), 3595--3631.
- N. Vieira, M. Ferreira, and M. M. Rodrigues, *Time-fractional telegraph equation with Ψ-Hilfer derivatives*, Chaos, Solitons & Fractals, 162 (2022), Article ID: 112276, 26pp.
- N. Vieira, M. M. Rodrigues, and M. Ferreira, *Time-fractional diffusion equation with Ψ-Hilfer derivative*, Computational and Applied Mathematics, **41**-No.6 (2022), Article ID: 230, 26pp.
- N. Vieira, M. Ferreira, and M. M. Rodrigues, Ψ-Hilfer fractional relaxation-oscillation equation, International Conference on Mathematical Analysis and Applications in Science and Engineering (ICMA²SC'22) - Book of Extended Abstracts, (2022), 163-166.
- M. M. Rodrigues, M. Ferreira, and N. Vieira, Some representations for the eigenfunctions of the time-fractional wave operator, International Conference on Mathematical Analysis and Applications in Science and Engineering (ICMA²SC'22) Book of Extended Abstracts, (2022), 245-248.
- M. Ferreira, M. M. Rodrigues, and N. Vieira, On a regular Ψ-fractional Sturm-Liouville problem, International Conference on Mathematical Analysis and Applications in Science and Engineering (ICMA²SC²2) - Book of Extended Abstracts, (2022), 167-170.
- S. Frassu, E. Rocha, V. Staicu, The Obstacle Problem at Zero for the fractional p-Laplacian. Set-Valued Var. Anal 30, 207–231 (2022). https://doi.org/10.1007/s11228-020-00562-0.
- S. Leonardi, F. Leonetti, E. Rocha, V. Staicu, Butterfly support for off diagonal coefficients and boundedness of solutions to quasilinear elliptic systems. *Adv.*

Nonlinear Anal. 11 (2022), no. 1, 672–683. <u>https://doi.org/10.1515/anona-2021-0205.</u>

2022 Talks

- A. Almeida, **[Plenary Talk]** The maximal operator in variable exponent Stummel spaces, XII Annual International Conference of Georgian Mathematical Union, Batumi (Georgia), August 29 September 3, 2022.
- A. Almeida, The maximal operator in variable exponent Stummel spaces: International Conference on Function Spaces and Applications, Apolda (Germany), October 1-7, 2022.
- A. Almeida, On the Riesz potential operator: a general framework for its inversion, 13th Annual Workshop of Functional Analysis and Applications Group, Department of Mathematics, University of Aveiro, September 28, 2022.
- A. Caetano, **[Invited Talk** in the parallel session Análise e Aplicações] A fractal approach to acoustic scattering by fractal screens, ENSPM 2022, 18-22 July 2022, Tomar, Portugal.
- A. Caetano, **[Invited Talk]** Functions Spaces and Techniques behind a Fractal Approach to Acousting Scattering by Fractal Screens, Function Spaces, Interpolation Theory and Related Topics 2022, 31 August to 1 September 2022, Madrid, Spain.
- A. Caetano, **[Plenary Talk]** A fractal approach to acoustic scattering by fractal screens, Function Spaces and Applications 2022, 1-7 October 2022, Apolda, Germany.
- L. P. Castro, **[Invited Talk]** Filter design based on the fractional Fourier transform associated with new convolutions and correlations, Workshop on Operator Theory, Complex Analysis, and Applications 2022 WOTCA 2022, University of Algarve on 20-24 June 2022.
- L. P. Castro, [Plenary Talk] New Convolutions and Some of Their Applications, XII INTERNATIONAL CONFERENCE OF THE GEORGIAN MATHEMATICAL UNION, Batumi, August 29 September 3, 2022.
- L. P. Castro, On the Solutions of a Fractional Boundary Value Problem with Integral Boundary Conditions, 13th Annual Workshop of Functional Analysis and Applications Group, University of Aveiro, September 2022.
- L. P. Castro, **[Invited Talk]** New convolutions generated by Hermite functions and consequent classes of integral operators, Tbilisi Analysis \& PDE Seminar, Institute of Mathematics of the University of Georgia, December 2022.
- L. P. Castro, **[Invited Talk]** On the solvability of a class of integral equations generated by multi-dimensional Hermite functions, ICOT 2022: International Conference on Operator Theory, Sousse (Tunisia), December 2022.
- H. Gonçalves, Embeddings of smoothness Morrey spaces on domains", GAFA Seminar (January);
- H. Gonçalves, On the compactness of embeddings between smoothness Morrey spaces, 13th Annual Workshop of Functional Analysis and Applications Group, University of Aveiro, September 2022.
- H. Gonçalves, Embeddings of Besov-type and Triebel-Lizorkin-type spaces on domains, online talk, Function Spaces and Applications 2022, 1-7 October 2022, Apolda, Germany.

- K. Murillo. 14th Annual international conference on education and new learning technologie, Palma, Spain, 2022. Communication title: About the quality and sustainable education in European countries: a comparative econometric analysis.
- K. Murillo. 31° International Statistics Symposio, Manizales, Colombia, 2022. Communication title: Implementing effective metrics in data analysis;
- K. Murillo. XIII International Conference Optimization and Applications, Petrovac, Montenegro, 2022. Communication title: Dynamical multidirectional efficiency analysis;
- K. Murillo. 13th Annual Workshop Functional Analysis & Applications Group, Aveiro, Portugal, 2022. Communication title: Non-parametric dynamic efficiency measurement;
- K. Murillo. International Conference on Economic, Athens, Greece, 2022. Communication title: Economic impact of the COVID-19 pandemic on production industry: a nonparametric comparative analysis;
- E. Rocha. IEEE 27th International Conference on Emerging Technologies and Factory Automation, Stuttgart, Germany, 2022. Communication title: Benchmarking and Prediction of Entities Performance on Manufacturing Processes through MEA, Robust XGBoost and SHAP Analysis;
- E. Rocha. Santiago de Compostela, Spain, 2022. Communication title: Understanding and predicting process performance variations of a balanced manufacturing line at Bosch.
- M. M. Rodrigues, Eigenfunctions-representations for the time-fractional wave operator, 28/9/2022, 13th Annual Workshop of Functional Analysis and Applications Group, University of Aveiro, Portugal.
- M. M. Rodrigues, *Distributed-order relaxation-oscillation equation*, International Conference of Numerical Analysis and Applied Mathematics ICNAAM 2022, 19-25/09/2022, Crete, Greece.
- M. M. Rodrigues, [Invited Talk] *Time-fractional telegraph equation of distributed order*, Encontro Conjunto Brasil-Portugal em Matemática, 14-20/08/2022, Federal University of Bahia, Salvador Bahia, Brazil.
- M. M. Rodrigues, Some representations for the eigenfunctions of the time-fractional wave operator, 27-29/06/2022, International Conference on Mathematical Analysis and Applications in Science and Engineering - ICMA²SC'22, School of Engineering of the Polytechnic of Porto, Porto, Portugal.
- A. Silva, "Stability results for a class of fractional four-point boundary value problems with Caputo derivative", International Conference on Fractional Calculus ICFC 2022, University of Hyderabad, India online event (January 18-19, 2022)
- A. Silva, "Ulam-Hyers-Rassias stability of a fractional boundary value problem with Caputo derivative", ISAME 2022 International Symposium on Applied Mathematics and Engineering, Istanbul, Turkey online event (January 21-23, 2022)
- A. Silva, "Existence and stability of solutions for a class of fractional boundary value problems", Turkish Journal Mathematics Webinar – Studies on Scientific Developments in Geometry, Algebra and Applied Mathematics, Turkey – online event (February 1-3 February 2022)

- A. Silva, "Fixed Point theory in the stability of fractional boundary value problems", Fourth Edition of the International Conference on Research in Applied Mathematics and Computer Science ICRAMCS 2022, Faculty of Sciences Ben M'sik, Hassan II University of Casablanca, Morocco – hybrid event (March 24-26, 2022)
- A. Silva, "On the stability of a boundary value problem with fractional derivatives", ICCMSO - International Conference on Advance Trends in Computational Mathematics, Statistics and Operation Research- online event, The NorthCap University, Gurugram, India - online event (April 2-3, 2022)
- A. Silva, "Fixed-point theorems applied to the study of fractional boundary value problems", First International Conference on Recent Researches in Mathematics FICRRM'22, Department of Mathematics, College of Natural and Computational Science, Mizan-Tepi University, Ethiopia online event (April 20-21, 2022)
- A. Silva, "Existence and uniqueness results for a fractional differential equation via fixed point techniques", Generalized Functions Online Workshop – 2nd edition – online event (May 12, 2022)
- A. Silva, "Stability analysis by fixed point theory for a class of nonlinear Caputo type fractional differential equations", WOTCA22 - Workshop on Operator Theory, Complex Analysis and Applications 2022, University of Faro, Portugal (June 20-24, 2022)
- A. Silva, "On the Ulam, Hyers and Rassias stabilities for a Caputo fractional boundary value problem of order greater than two", International Conference on Mathematical Analysis and Applications in Science and Engineering – ICMA2SC'22, ISEP, Porto, Portugal (June 27-29, 2022)
- A. Silva, "Analysis of differential equations with derivatives of integer and fractional order", International Conference on Mathematical Analysis and Applications 2022, Department of Mathematics, University of Kalyani, India – online event (June 29, 2022)
- A. Silva, "Existence and stability results for a nonlinear fractional boundary value problem", 13th Annual Workshop of Functional Analysis and Applications group, University of Aveiro (September 28, 2022)
- A. Silva, "Existence, uniqueness and stability to a class fractional order differential equations", Workshop "Recent Advances in Analysis and Applications", College of Science United Arab Emirates University hybrid event (October 19-20, 2022)
- V. Staicu, "On some nonlinear parabolic equations with non-monotone multivalued terms", National conference of the Portuguese Society of Mathematics (ENSPM), July 18-20, 2022, Tomar.
- V. Staicu, "On some quasilinear parabolic equations with non-monotone multivalued terms, 13th Annual Workshop of Functional Analysis and Applications Group, Department of Mathematics, University of Aveiro, September 28, 2022.
- V. Staicu, **[Invited Talk]** "Existence of solutions to boundary value problems with nonsmooths and multivalued terms", the Applied Math seminar of Mathematical Institute, Tohoku University, Japan.

- V. Staicu, **[Invited Talk]** "On some quasilinear parabolic equations with non-monotone multivalued terms", invited talk at RIMS workshop "Innovation of the theory for evolution equations: developments via cross-disciplinary studies", October 17-19, RIMS, Kyoto University, Japan.
- V. Staicu, "Boundary value problems with nonsmooths and multivalued terms", three talks at Mathematical Institute, Tohoku University, Japan, October 25-27.
- V. Staicu, "On some parabolic equations with non-monotone multivalued terms", DISIM Seminar, University of L'Aquila, November 30, 2022.
- V. Staicu, "On some parabolic equations with non-monotone multivalued terms: global existence and applications", DISIM Seminar, University of L'Aquila, December 12, 2022.

2022 Organization of Scientific Events

- 13th Annual Workshop of Functional Analysis and Applications Group, Department of Mathematics, University of Aveiro, September 28, 2022.
- Symposium Fractional differential theory and applications, International Conference on Mathematical Analysis and Applications in Science and Engineering – ICMA²SC²22, Polytechnic of Porto. School of Engineering, Portugal, 27-29/06/2022. Organized with M. Ferreira and N. Vieira.
- Symposium *Fractional Differential Calculus and Clifford Analysis*, International Conference of Numerical Analysis and Applied Mathematics ICNAAM 2022, Crete, Greece, 19-25/09/2022. Organized with N. Vieira, R.S. Kraußhar, and K. Gürlebeck.

2022 Visitors

- June 13 19: Alberto Bressan, Penn State University, EUA
- June 20 24: Bruno Rubino, University of L'Aquila, Italy.
- July 7 8: Antonio Iannizzotto, University of Cagliari, Italy.

October 18 – 28: Roland Duduchava, Institute of Mathematics, University of Georgia & A. Raznmadze Mathematical Institute, Georgia.

October 18 – 28: Margarita Tutberidze, Institute of Mathematics, University of Georgia, Georgia.

November 6 – 15: Nguyen Minh Tuan, University of Education, Viet Nam National University, Viet Nam.

2022 Visits

July 11 – 15: L. P. Castro, Department of Mathematics of UBI, Universidade da Beira Interior, Portugal.

October 1 – 31: V. Staicu, Mathematical Institute and Graduate School of Sciences, Tohoku University, Sendai, Japan, as a JSPS Invitational Fellow.

November 15 – December 15: V. Staicu, Department of Engineering, Information Sciences and Mathematics of the <u>University of L'Aquila</u> (DISIM).

Thematic Line TFC - From Theory to Computational Frameworks (Coordinated by the GAFA member Eugénio Rocha)

In the LT-TFC, the following <u>mathematical computational frameworks</u> were implemented in 2022:

- [F01] Variables influence analysis of gas leak testing using belief propagation over factor graphs (J. Martins³, D. Costa¹, E. Rocha) – use case at Bosch TT;
- [F02] Predictive system for stocks improvement in the ceramic industry (P. Lobo⁴, E. Rocha) use case at Aleluia Cerâmicas;
- [F03] An IoT proposal for injection mold data retrieving (B. Mendes², R. Antunes, E. Rocha, J. Santos) use case at OLI;
- [F04] Recommendation system in PCBA repair (J. Cozinheiro¹, E. Rocha, J. Santos) use case at Bosch BT;
- [F05] Convolutional neural networks for identification of moving combustion chambers entering a brazing process (R. Pereira¹, E. Rocha, D. Pinto, J. Santos) – use case at Bosch TT.
- [F06] Identificação de fatores relevantes em problemas de qualidade e manutenção numa empresa de porcelana (B. Rato¹, E. Rocha) – use case at Vista Alegre.
- [F07] Metodologias Bayesianas na Avaliação do Risco e Progressão da Degenerescência Macular da Idade (M. Inês Silva¹, E. Rocha) – study data of AIBILI.

The LT-TFC did not spend any financial resources during 2022 in grants. All work was done by integrated students and/or LT-TFC members. The frameworks [F03] and [F04] are deployed in edge devices in the shopfloor of the industrial companies, being used every day. [F01] and

³ PhD student (co)supervised by E. Rocha

⁴ MSc student (co)supervised by E. Rocha

[F02] have corresponding publications accepted in 2022. Works [F02]-[F07] produced 6 Master Theses, available at RIA/UA.

2022 TFC Talks:

- E. Rocha, 4th International Conference on Industry 4.0 and Smart Manufacturing, Linz, Austria, 2022. Communication title: Convolutional neural networks for identification of moving combustion chambers entering a brazing process;
- E. Rocha was a tutor/scientific committee member in the VII Iberian Modelling Week, Coimbra, Portugal, 2022, for the problem 4.

List of the 2022 Talks in the GAFA Seminar

- Helena Gonçalves (CIDMA, University of Aveiro), "Embeddings of smoothness Morrey spaces on domains", January 20
- Andrea Moiola (University of Pavia, Italy), "Stable approximation of Helmholtz solutions by evanescent plane waves", March 17
- Rúben Sousa (CMUP, University of Porto), "Convolution-like structures, differential operators and diffusion processes", March 30
- Silvia Frassu (Department of Mathematics and Computer Science, University of Cagliari, Italy), "Multiple solutions for the fractional p-Laplacian with jumping reactions", April 21
- Nelson Vieira (CIDMA, University of de Aveiro), "On the fundamental solution of the Psi-Hilfer fractional diffusion equation and its probabilistic interpretations", May 5
- Carla M. A. Pinto (CMUP & ISEP Instituto Superior de Engenharia do Porto), "The pandemic seen from a simple mathematical model perspective", June 2
- Evgeny Lakshtanov (CIDMA, University of Aveiro), "Adjoint differentiation for generic matrix functions", 9 June
- Simão Correia (CAMGSD, Instituto Superior Técnico, University of Lisbon), "The infinite normal form reduction for nonlinear dispersive equations", June 15
- Alberto Bressan (Penn State University, USA), "Optimal control of propagation fronts and moving sets", June 17
- Milton Ferreira (Polytechnic Institute of Leiria & CIDMA), "Quaternion hyperbolic Fourier transforms", September 21
- Roland Duduchava (The University of Georgia, A. Razmadze Mathematical Institute, Tbilisi, Georgia), "Convolution equations on the Lie group G=(-1,1) and their applications", October 19
- Margarita Tutberidze (Institute of Mathematics of the University of Georgia, Tbilisi, Georgia), "Mixed type boundary value problems for the Helmholtz equation in a model 2D double angular domain", October 19
- Fábio Chalub (Faculdade de Ciências e Tecnologias, University Nova de Lisboa), "The Variational Formulation of Evolutionary Processes", October 27

- Nguyen Minh Tuan (Viet Nam National University, Ha Noi, Viet Nam), "On norm decay rates of the Fourier oscillatory integral operators with real-valued phases", November 9
- Clara Carlota (CIMA, University of Évora), "On existence of solutions for optimal control problems with nonconvex lagrangian", November 24
- José Joaquim Oliveira (CMAT & University of Minho), "Global exponential stability criterion for a general system of difference equations with unbounded delays and applications to discrete-time neural network models", December 7

2023 Functional Analysis and Applications Group (GAFA) Plan of Activities

Members (with PhD):

António Manuel Rosa Pereira **Caetano** Anabela de Sousa e **Silva** Eugénio Alexandre Miguel **Rocha** Helena Daniela Ferreira **Gonçalves** José Alexandre Rocha **Almeida** Kelly **Murillo** Luís Filipe Pinheiro de **Castro (group leader)** Maria Manuela Fernandes **Rodrigues** Vasile **Staicu**

Member without PhD (PhD Student):

Joana Dirce Santos Martins

Collaborators:

Ana Paula Branco Nolasco (Universidade de Aveiro) Alberto Manuel Tavares Simões (CMA – Centro de Matemática e Aplicações, UBI) Rita Catarina Correia Guerra (CMUC – Centro de Matemática, Universidade de Coimbra) Sandrina Rafaela Andrade Santos (Universidade de Aveiro)

We will study the deformation of unit balls in Lebesgue spaces of higher dimension, its implications on established functional analysis results, and their practical effect on the study of high-volume data. Development of a new mathematical metric to score data complexity, allowing an efficient way to determine data drift in streaming data. Extension of the GFT theory, previously introduced by the group, into root cause analysis of hybrid systems, involving differential equations and discrete state transitions with applications to simulation of complex systems. Notice that GFTs are a mathematical generalization of a theory used in reliability analysis at NASA and TESLA. Widen the applications to new areas as energy devices (e.g., heat pumps) and to logistic processes (e.g., container multimodal transportation). Study the application of factor graphs and belief propagation in numerical techniques for solving functional analysis problems. Introduce a generalization of the classical statistics suited for nonlinear time-varying data, by introducing a functional analysis viewpoint on the moments' calculation. Application of some of the results obtained in 2022 to medical data.

Focus on evaluating and determining a relative ranking in efficiency analysis models, which allows studying the evolution over time, through appropriate mathematical models. In this sense, next year, we intend to explore two lines of action: (a) combine the proposed dynamic

MEA model with the index numbers technique (Laspeyres, Paasche, Törnqvist, Fischer, Malmquist, Luenberger). This means incorporating new indices in the model, to investigate the total productivity factor, the specific variable productivity change, among other relevant aspects in this type of studies; and (b) determine adjustment models (either to study situations where there is not enough data and/or to predict future situations), which allow for a comparative efficiency analysis over time.

We plan to continue the research of variable exponent Stummel spaces in order to understand how some classical operators from harmonic analysis behave in these spaces. This is important not only from theoretical purposes but also by the important role played by Stummel spaces in applications to partial differential equations. Moreover, we expect to conclude the general inversion scheme for the Riesz potential operator. This project has two main goals: firstly, one aims to obtain inversion results in new function spaces; at the same time, one plans to develop the point of view of systematization of various existing results in different function spaces.

It is also expected that some embeddings on the 2-microlocal Besov-type and Triebel-Lizorkintype spaces with variable exponents will be obtained - using the already proven tools. Moreover, embeddings on the scale generalized Besov-Morrey spaces on domains will also be considered.

Continue the collaboration with the co-authors S. Chandler-Wilde, A. Gibbs, D. Hewett, A. Moiola (of the manuscript submitted to publication "A Hausdorff-measure boundary element method for acoustic scattering by fractal screens"), namely considering the case where the screen has Hausdorff dimension equal to the dimension of the "support" space, although it can still be a quite irregular set (e.g., having a fractal boundary).

Resume research on function spaces with variable parameters, namely exploring the issue of duality. Probable application to form a Topical Activity Group on Harmonic Analysis and Function Spaces under the umbrella of the EMS and together with several colleagues across Europe.

We will continue to study regularity properties of classes of integral operators and integral equations, as well as integral transforms and their potential applications. In the latter case, special emphasis will be given to obtaining different types of uncertainty principles.

We will also continue to analyse classes on differential and integral equations, of various kinds, involving fractional derivatives (such as those of Riemann-Liouville, of Caputo or their generalizations) and integration, focusing on fundamental properties of their possible solutions, such as the existence and uniqueness of solutions, and their stability. A detailed emphasis will be given to the study of the fractional Helmholtz operator, the study of the fractional gradient defined in terms of ψ -Hilfer fractional derivatives and development of a numerical method to solve optimization problems.

Finish the project of writing an introductory book on the Theory of Function Spaces (A. Almeida and A. Caetano).

The joint research initiated during the visit at Tohoku university concerning existence and multiplicity of solutions to Dirichlet problems involving the 1-Laplacian and to some degenerate parabolic equation associated with the *p*-Laplacian will be continued in 2023.

The study of "Controlled Set Motion in a Bounded Domain" in collaboration with Alberto Bressan initiated during his visit in Aveiro, will be continued in 2023. We consider a family of geometric evolution problems, modeling the control of an invasive population within a bounded domain, that can be recovered as simplified models of control of parabolic reaction-diffusion equations.

The study of existence and multiplicity of solutions with boundary value problems for elliptic and parabolic differential inclusions will be continued and an introductory monography is planned to be written.

The joint work with F. Leonetti and S. Leonardi concerning boundedness of solutions to some quasilinear elliptic systems will be continued in 2023.

2023 Outreach Activities

- A. Caetano is Vice-President of CIM, still with an increased involvement in the activities of the Centre due to health restrictions of the President.
- A. Caetano will continue the mandate as delegate at the EMS Council representing its institutional members.
- A. Caetano will continue the supervision *pro bono* of one of the grantees from the program Novos Talentos, in Mathematics, from the Calouste Gulbenkian Foundation. The activities should be finished by September of 2023.
- L. P. Castro is part of the evaluation committee of a European university (with more than 35 000 students) within the scope of the Institutional Evaluation Programme of the European University Association.
- V. Staicu is the Interim Vice-President of the American Romanian Academy of Arts and Sciences (ARA) (http://main.ara-as.org), Member of the Board of Directors of ARA in charge with the publications of ARA and Editor in Chief of the mathematical journal Libertas Mathematica (new series) edited in Aveiro with partial support from CIDMA under the auspices of ARA (http://system.lm-ns.org/index.php/).
- V. Staicu is the Local Coordinator at the University of Aveiro of the consortium RealMaths Mathematics for Real World Applications, a set of 2-year Double MSc programmes with focus on scientific computing and applications. Students spend one year at the University of L'Aquila and one year in one of the partner institutions.
- V. Staicu is a member of the "Fundamental Research" section of the "Register of Expert Peer Reviewers for Italian Scientific Evaluation (REPRISE database) (<u>https://reprise.cineca.it/</u>) of the Ministry of University and Research (MIUR) of Italy.

2023 Organization of Scientific Events

- We will continue to organize the (already classic) GAFA Group Seminar.
- 14th Annual Workshop of Functional Analysis and Applications Group, Department of Mathematics, University of Aveiro.
- Co-organization of the WOTCA 2023 Workshop on Operator Theory, Complex Analysis, and Applications, University of Aveiro.
- Organization of one special session about Fractional Calculus at one international conference.

Thematic Line TFC - From Theory to Computational Frameworks (Coordinated by the GAFA member Eugénio Rocha)

In 2023, the LT-TFC activities will focus mainly on the implementation of mathematical computational frameworks for the fish and agriculture industry with close collaboration with SEA8 company with the integration of sensors developed by members of I3N.

Annual report 2022 - Gravitational Geometry and Dynamics Group (GGDG)

In 2022 the GGDG group continued to develop its scientific activities focusing on mathematical physics, strong gravity and high energy physics.

GGDG members have co-authored 39 publications in international journals with refereeing including Physical Review D (20 papers), Physics Letters B (5 papers), Classical and Quantum Gravity (4 papers), Journal of High Energy Physics (JHEP - 3 papers), European Physics Journal C (EPJC - 2 papers), Physical Review Letters (1 paper, as editor's suggestion), International Journal of Modern Physics D (IJMPD - 1 paper), Living Reviews in Relativity (1 paper), Journal of Cosmology and Astroparticle Physics (JCAP - 1 paper) and European Physics Letters (EPL - 1 paper).

GGDG group members presented over 40 invited and conference oral communications, (both onsite and online, including mini-courses) in many institutions/conferences in countries including Austria, Belgium, Brazil, Canada, Chile, China, Ecuador, France, Ireland, Israel, Germany, Mexico, Portugal, Romania, Spain, and USA.

The GGDG group organized 25 Scientific Seminars (both online and onsite), mostly by non-UA scientists and 18 Journal Clubs as group activities. Group members co-organized also 7 events in Portugal, Spain and Brazil, only two of which at the University of Aveiro.

GGDG group members gave 12 outreach lectures/talks for the general public in their scientific areas and participated in several outreach initiatives, including an appearance in Portuguese National TV, in the show UAU, "Science without limits", co-produced by RTP and the University of Aveiro.

In terms of distinctions, 4 group members were ranked, in the 2022 Stanford researhers ranking led by John Ioannidis, as belonging to the top 2% of their field worldwide, either in their career or in the year of 2021. As another distinction, the essay "On the classicality of bosonic stars" by C. Herdeiro and E. Radu was awarded an honorable mention in the 2022 Gravity Research Foundation Essay competition. As another distinction, C. Herdeiro was appointed member of the editorial board (associate editor) of the European Physical Journal C (EPJC), for the section "Theoretical Physics III: Quantum Field Theory and Gravity - Fundamental and Formal Aspects". EPJC is a leading international journal on this research topic with over 2M downloads in 2021 and an impact factor of 4.590 (2020).

In 2022, the group got funded two CERN/FCT projects (PI: C. Herdeiro and A. Morais), one PTDC project (PI: M. Zilhão), got awarded 3 positions in the individual CEEC call (M. Zilhão, G. Raposo and H. Olivares) and got awarded a new staff exchange network grant - NewFunFiCO - within the Horizon-MSCA-2021-SE-01 call (global PI: C. Herdeiro). The network has nodes at Aveiro University (Portugal, coordinator), University of Valencia (Spain), Johann Wolfgang Goethe-Universitaet Frankfurt Am Main (Germany), Universidad Nacional Autonoma de Mexico (Mexico), Universidade Federal do Pará (Brazil) and the Chinese University of Hong Kong (China). The network will start on January 1st 2023 and have a lifetime of 4 years. The group got also awarded 2 new Ph.D. grants (M. Brito and E. Costa Filho).

In 2022, our group joined the European Consortium for Astroparticle Theory (EuCAPT) and the group successfully concluded 2 Ph.D. thesis in 2022 (Alexandre Pombo and Jorge Delgado).

Activities plan for 2023

In 2023 the group will continue to develop its scientific activities focusing on mathematical physics, strong gravity and high energy physics. The group is planning to continue with its Seminar and Journal Club programme, to continue to host scientific guests, including two foreign professors in Sabbatial leave and to organize one event at the University of Aveiro (The workhop on the Einstein Toolkit).

CIDMA - Relatório FCT Contributions 2022 of GHMEM

Resumo dos trabalhos

The group's activities are focused on the History of Mathematics and Mathematics Education. In 2022, H. Pinto in the Advisory Board, T. Costa Clain and C. Costa in the Consultative Commission collaborate with the International Study Group HISTORY and PEDAGOGY of MATHEMATICS. H. Pinto was co-chair of the 9th European Summer University on History and Epistemology in Mathematics Education in 2022 in Salerno (Italy). P. Oliveira and L. Descalço are continuing to develop new educational tools with the aim of creating an intelligent tutoring system to support self-study in Mathematics. The high participation in several international conferences after the pandemic 2020/21 in the field of History of Mathematics and Mathematics Education as well as the visits of Snezana Lawrence (UK) and Iran Mendes (Brazil) have a very positive impact on the internationalization of the research group.

Desvios dos trabalhos face à proposta aprovada

Due to pandemic and war, several international events did not take place or were postponed. Consequently, some invitations from historians, research stays abroad and participations in congresses could not be realized.

Indicadores A. Publicações

Livros (1)

Pinto, H., Silva, A., Magalhães, C. & Figueiroa, A. (2022). Vamos marcar um livro na Matemática? Cultura Editora e Federação Portuguesa de Futebol, (2022). 96 p.

Capítulos em livro (9)

L. Descalço, P. Carvalho: An experiment with serious games on mathematics in higher education. Proceedings of EDULEARN22 Conference, July 2022, Palma de Maiorca (Spain), International Academy of Technology, Education and Development (IATED), 3899-3903, Palma, Spain, 2022. (<u>http://hdl.handle.net/10773/35354</u>)

L. Descalço, P. Carvalho: Effective learning in mathematics. Proceedings of EDULEARN22 Conference, July 2022, Palma de Maiorca (Spain), International Academy of Technology, Education and Development (IATED), 3870-3876, Palma, Spain, 2022. (<u>http://hdl.handle.net/10773/35355</u>)

M.P. Oliveira: Mathematics, Computers and Competitions: 30 years together. Proceedings of EDULEARN22 Conference, July 2022, Palma de Maiorca (Spain), International Academy of
Technology, Education and Development (IATED), 1422-1430, Palma, Spain, 2022 (<u>http://hdl.handle.net/10773/35411</u>)

L. Dias, **M. P. Oliveira** e N. R. O. Bastos: An experience with Desmos in the study of quadratic function. Proceedings of EDULEARN22 Conference, July 2022, Palma de Maiorca (Spain), International Academy of Technology, Education and Development (IATED), 4456-4464 Palma, Spain, 2022 (http://hdl.handle.net/10773/35412)

Cação, Isabel; Falcão, M. Irene; **Malonek, Helmuth R**.; Tomaz, Graça: Non-symmetric number triangles arising from hypercomplex function theory in R(n+1), Lecture Notes in Computer Science (LNCS,volume 13377), 420–434 (2022) Springer Nature Switzerland AG, (<u>http://hdl.handle.net/10773/35389</u>) [in GACH?]

Não podiam estar incluídos no relatório do ano 2021:

M. P. Oliveira: PmatE: um projeto com vida (longa). In: Santos, Vanda; Cabrita, Isabel; Neto, Teresa B.; Pinheiro, Margarida M.; Lopes, J. Bernardino (Eds.) Matemática com vida: diferentes olhares sobre a Tecnologia. UA Editora. Dezembro 2021. <u>http://hdl.handle.net/10773/32770</u>.

D. Seabra, J.P. Cruz, L. Descalço, P. Carvalho and **P. Oliveira:** Computadores no apoio ao estudo autónomo e avaliação em Matemática. In: Docência da Matemática no Ensino Superior, Coleção "Estratégias de Ensino e Sucesso Académico: Boas Práticas no Ensino Superior", vol. 9. Ed. CINEP - Centro de Inovação e Estudo da Pedagogia no Ensino Superior, Instituto Politécnico de Coimbra (IPC) (2021). (<u>http://hdl.handle.net/10773/35415</u>)

Andrade, A., **Malonek, H**., Malaquias, I., Saro, J., Bonifácio, V.: The project "Science Stories in the School Library", in: Ana Luísa Santos, Ana Isabel Simões Rola, Carla Morais, Clara Vasconcelos, Elsa M. C. Gomes, Isilda Teixeira Rodrigues, Jorge Azevedo, Sérgio P. J. Rodrigues (Eds.) History of Science in Science Teaching. Revisiting Approaches, Innovating Knowledge, 421-442, Imprensa da Universidade de Coimbra (2021)

Artigos em revistas internacionais (0) Artigos em revistas nacionais (0)

B. Comunicações

Comunicações em encontros científicos internacionais (15)

H. R. Malonek: Appell Functions in the Theory of Hyperholomorphic Functions, International Conference on Mathematical Analysis and Differential Equations, Sept. 2022, Tsakhkadzor (Armenia) [in CHAG ?] **H. R. Malonek:** Mathematics with its history hand in hand - Suggestions for Integrative Teaching history of mathematics for students of mathematics, Conference on Teaching History of Sciences, SFU, Research Center of Mathematics, Febr. 9. 2022, Rostov-on-Don (Russia)

P. Kharazmi: From Beremiz to Abu Sahl al-Kuhi - moments in the history of the Heptagon 9° Encontro Luso-Brasileiro de História da Matemática, Oct. 2022, Setúbal (Portugal)

H. R. Malonek: Coimbra 1927 – episode in the life of the Russian - Ukrainian mathematician Nikolay Mitrofanovich Kryloff

9° Encontro Luso-Brasileiro de História da Matemática, Oct. 2022, Setúbal (Portugal)

J. Carvalho e Silva, **T. Costa Clain:** A divulgação da História da Matemática através dos manuais escolares do 7ºano publicados em 2022",

9° Encontro Luso-Brasileiro de História da Matemática, Oct. 2022, Setúbal (Portugal)

P. Oliveira: On Math's Education in Portugal and Greece in the final of 19th, beginning of 20th centuries,

9° Encontro Luso-Brasileiro de História da Matemática, Oct. 2022, Setúbal (Portugal)

P. Oliveira: Mathematics, Computers and Competitions: 30 years together. EDULEARN 22 conference. July 2022, Palma Maiorca, (Spain)

P. Oliveira, L. Dias, M. P. Oliveira e N. R. O. Bastos: An experience with Desmos in the study of quadratic function. EDULEARN 22 conference. July 2022, Palma Maiorca, (Spain)

H. Pinto, A. P. Martins, H. Gomes e L. Menezes: "Portuguese teachers' conceptions and practices on the history of mathematics in teaching (7th to 12th grades),

9th European Summer University on History and Epistemology in Mathematics Education,July 2022, Fisciano (Italy)

H. Pinto, C. Costa and **H. Malonek**: History of Mathematics in Portuguese textbooks of Vicente Gonçalves (1896-1985) and José Sebastião e Silva (1914-1972),

9th European Summer University on History and Epistemology in Mathematics Education,July 2022, Fisciano (Italy)

H. Pinto, A. P. Martins**:** A História da Matemática na formação e na prática profissional dos professores portugueses

9° Encontro Luso-Brasileiro de História da Matemática, Oct. 2022, Setúbal (Portugal)

H. Pinto: "História e Pedagogia da Matemática: uma ligação com mais de 40 anos de história" na "V Escola de Estudos Avançados – Pesquisa em Cultura, História e Educação" (Universidade Federal do Pará; online), Fevereiro de 2022.

H. Pinto: História e Pedagogia da Matemática: uma ligação com mais de 40 anos de história, Universidade de Cabo Verde, Setembro de 2022.

H. Malonek: Porque é que a História da Matemática é útil para o Ensino da Matemática? Argumentos e exemplos. Universidade de Cabo Verde, Maio de 2022.

D. Tavares: Frational variational problem of Herglotz type involving arbitrary kernels, ICNAAM 2022, Sept. 2022, Heraklion (Greece) [in SCG ?]

Comunicações em encontros científicos nacionais (9)

Parisa Kharazmi: Polígonos Regulares e Proporções - um Capítulo Esquecido na História da Matemática. 35° Encontro do Seminário Nacional de História da Matemática, Gouveia, Junho de 2022.

H. R. Malonek: Químico, matemático amador e poeta: Frederick Soddy – Nobel 1921. 35° Encontro do Seminário Nacional de História da Matemática, Gouveia, Junho de 2022. Gouveia, Junho de 2022.

P. Oliveira: About 33 years of the Project Matemática Ensino, 6th Annual Workshop of the History of Mathematics and Mathematical Education Group, Aveiro, May 14, 2022.

T. Costa Clain: Arithmetic in the Bibliotheca do Povo e das Escolas, 6th Annual Workshop of the History of Mathematics and Mathematical Education Group, Aveiro, May 14, 2022.

L. Descalço: Web applications for mathematics learning from DMat-UA, 6th Annual Workshop of the History of Mathematics and Mathematical Education Group, Aveiro, May 14, 2022.

P. Oliveira: 33 anos do Projecto Matemática Ensino.

35° Encontro do Seminário Nacional de História da Matemática, Gouveia, Junho de 2022. Gouveia, Junho de 2022.

H. Pinto: Teachers' Conceptions and Practices on the History in Mathematics Teaching in the 5th and 6th grades in Portugal,

6th Annual Workshop of the History of Mathematics and Mathematical Education Group, Aveiro, May 14, 2022.

H. Malonek: Remarks on an article of I. Grattan-Guinness in HISTORIA MATHEMATICA 23 6th Annual Workshop of the History of Mathematics and Mathematical Education Group, Aveiro, May 14, 2022.

Parisa Kharazmi: The Mystery of Ratios and Proportions in Pentagon & Heptagon, 6th Annual Workshop of the History of Mathematics and Mathematical Education Group, Aveiro, May 14, 2022.

C - Relatórios (0)

D. Organização de seminários e conferências (2)

H. Pinto: Co-chair of the 9th European Summer University on History and Epistemology in Mathematics Education (ESU-9), Italy, 2022

H. Pinto: Co-chair of Painel 5 online: História da Matemática em múltiplas imagens e vídeos: implicações socioculturais na aprendizagem e no ensino e interdisciplinar da matemática,

THEMA, 1st Colóquio Inter-Latino on relations between Technologies and History of Mathematics for Teaching

E - Formação avançada

Teses de Mestrado (8)

M. Sc. Mathematics and Applications, Universidade de Cabo Verde, 2022:

História do Ensino da Matemática na Formação de professores para o ensino secundário em Cabo Verde.

Mário dos Santos Fernandes

Supervision: Helmuth Malonek and Helder Pinto, Cidade da Praia, 2022.

Avaliação na disciplina de Matemática. Janilson de Jesus Semedo Pereira, Supervision: **Maria Paula Oliveira** and Sandra Diogo Ramos, 2022.

Estratégias dinâmicas de aprendizagem em Matemática no domínio da Trigonometria. José Manuel Fernandes Moreira Supervision: **Maria Paula Oliveira** and **Dina Seabra**, 2022.

Estratégias dinâmicas de aprendizagem em Matemática no domínio da Geometria. Manuel de Jesus Pires Tavares, Supervision: **Maria Paula Oliveira** and **Dina Seabra**, 2022.

M. Sc. Matemática para Professores, Universidade de Aveiro, 2022:

A Matemática do Ensino Básico numa abordagem STEAM. Maria Clarisse Ribeiro Soares, Supervision: **Maria Paula Oliveira** and Sandra Diogo Ramos, 2022.

Aprendizagens ativas nos domínios da estatística e das probabilidades com recurso a ferramentas digitais.

Isabel Cristina Barbosa Ferreira,

Supervision: Maria Paula Oliveira and Nuno Rafael Oliveira Bastos, 2022.

Impacto de práticas de avaliação formativa na qualidade do sucesso dos alunos de matemática ensino secundário.

João Álvaro Cunha das Neves,

Supervision: Maria Paula Oliveira. 2022. (http://hdl.handle.net/10773/34567)

Estratégias dinâmicas de aprendizagem em Matemática no domínio da Trigonometria. Maria João da Silva Barroso,

Supervision: Maria Paula Oliveira and Dina Seabra, 2022. (http://hdl.handle.net/10773/34568)

G - Aplicações computacionais (2)

Luís Descalço: Major improvements in the two applications SIACUA and MCQ Editor: https://siacua.web.ua.pt/, https://mcqeditor.web.ua.pt/

M. Outros indicadores:

Helder Pinto:

Member of the Advisory Board of the International Study Group HISTORY and PEDAGOGY of MATHEMATICS (HPM, an organization affiliated to the ICMI of IMU),

Teresa Costa Clain:

Elected member of the Consultative Commission of HPM

H. Pinto: No âmbito do Ciclo de Conferências - Histórias com Ciência na Biblioteca Escolar: Problemas Reais – Soluções Matemáticas Históricas, Março 2022, Escola Secundária Júlio Dinis (Ovar)

Plano do grupo de HMEM para 2023

I. Projetos:

1º Realizar o 36º Encontro do SNHM em Aveiro no início de outubro. A candidatura formal à direção do SNHM está no anexo. Há já uma aceitação informal e espera-se ter uma resposta definitiva muito em breve.

2º Junto com a UF de Pará (Iran Mendes) membros do grupo(em particular o Helder Pinto) preparam um convénio de colaboração que incluía a orientação de teses de formação. Iran Mendes esteve uma semana em Aveiro e mantém contactos permanentes connosco.

3º Na base da composição atual variada do grupo está a ser estudado, junto com o Prof. Jaime de Carvalho e Silva, a criação de um centro de formação de professores do Ensino Escolar (EB e ES) para apoiar a aplicação adequada de assuntos de História da Matemática nos novos programas (uma ideia a ser desenvolvido em colaboração com o Prof. Jaime de Carvalho e Silva, Teresa Costa Clain - atualmente formadora acreditada pelo Ministério, Helder Pinto e outros). O projeto permitia focar as competências de um grande número de colegas do grupo a um a um objetivo comum.

II. Convites de colaboradores estrangeiros:

Está previsto o convite de 2 estrangeiros (já previamente contactados) com verbas de GACH para o encontro de SNHM e de mais 2-3 para realizar investigação em áreas comuns. (Na jornada vou explicar como se desenvolveram durante o ano 2022 novas ideias para "networking" e aumento da internacionalização. Assim será possível organizar vários seminários, entre outro também ao nível departamental ("A História e a Herança da Matemática").

III. Missões:

Depois de ter auscultados os planos de alguns membros conto com visitas de estudo e participações em conferências de pelo menos 5-6 membros/colaboradores do grupo, seguindo ao bom exemplo do ano 2022.

36.º Encontro do Seminário Nacional de História da Matemática (SNHM) 2023

Proposta

Local: Departamento de Matemática da Universidade de Aveiro

Datas: a definir.

<u>Sugestão</u>: durante o mês de maio/junho, coincidindo com o final do ano letivo e sendo um mês favorável para deslocações de participantes internacionais, por não coincidir com a época alta em termos de turismo.

Responsável pela organização local: Helmuth R. Malonek, Responsável Científico do grupo de investigação em História da Matemática e Educação Matemática (HMEM) da UI&D CIDMA com o apoio de outros membros do grupo.

Apoio científico e logístico: CIDMA-GHMEM da Universidade de Aveiro O apoio logístico será ainda complementado pela *Escola de Formação Profissional em Turismo de Aveiro* (EFTA).

Oradores convidados:

Neste evento contaremos com a participação de dois oradores internacionais com um relevante currículo na área da História da Matemática.

Apoio Financeiro:

Será solicitado apoio financeiro ao CIDMA e a entidades locais, entre outras opções.

Alojamento e acessos:

Sendo Aveiro uma cidade localizada na zona litoral, existem excelentes acessos à cidade e, em particular, à Universidade de Aveiro, bem como uma diversa oferta de transportes públicos.

Para participantes internacionais e que cheguem a Portugal através de avião, existem ligações diretas, via comboio, até à cidade de Aveiro.

Aveiro, 11.10.2022.

H. R. Malonek

OTGC

Resumo dos trabalhos do ano 2022:

An important contribution was made to the study of faithful permutation representations of the groups of abstract regular polytopes. Spectral radius of the generalized adjacency matrix of a digraph was studied, and the spectrum of a family of integral mixed graphs was characterized. The work on study of conic and copositive programming problems was continued, and in particular, equivalent representations of faces of the cone of copositive matrices were obtained, and methods of regularization of copositive problems were developed. Optimization models were proposed for inventory-routing and berth allocation problems. MIP model-based heuristics for the minimum weighted tree reconstruction problems was developed, and weighted iterated local branching for mathematical programming problems with binary variables was constructed. The characterization of the integer eigenvalues (and respective multiplicities) of the n-Queens graph was obtained. Sharp bounds on the least eigenvalue of a graph determined from edge clique partitions were found. Lexicographic products with invariant main eigenvalues were investigated. A full classification of self-adjoint extensions of the Laplace operator on Grushin manifolds was obtained, and an algorithm for computation of the determinant and Morse index of large symmetric block Jacobi matrices was developed. It was proved that a convex body solving the generalized Newton's least resistance problem is uniquely defined by the set of its singular points. Local structure of convex surfaces near regular and conical points was described.

Publicações

Livros – 1 Capítulos de livros -- 4 Artigos em revistas internacionais -- 25 Artigos em revistas nacionais -- 0 **Comunicações** Comunicações em encontros científicos internacionais -- 20 Comunicações em encontros científicos nacionais -- 2 **Organização de seminários e conferências** -- 4

Teses de Doutoramento -- 1

Teses de Mestrado - 15

Participação em projetos:

- SMART-QUAL Structured indicators to manage HEI Quality System (Erasmus+ 2020-1-BE01-KA203-074900) – 1 paper, 1 international presentation, 1 national presentation
- O3F An Optimization Framework to reduced Forest Fire (PCIF/GRF/0141/2019) 1 national presentation
- Augmanity - Augmented Humanity (POCI-01-0247-FEDER-046103) no outputs to report.

Websites gerados

- Website of the One Day Workshop in Differential Geometry: <u>https://sites.google.com/view/dgaveiro</u>
- Website for the 9th International Conference on Matrix Analysis and Applications (ICMAA 2022): <u>https://sites.google.com/view/icmaa-2022</u>

Outras ações públicas

Maria Elisa Fernandes:

Award: Chair Internationale IN from ULB

• Participation on UAU-Ciência sem limites RTP3 and on UAUPodcast Piloto

Planos para 2023:

Solve some enumerating and classification problems in the theory of abstract polytopes, in particular, find a formula for the number of abstract regular polytopes of high rank, and give a classification of maximal rank abstract regular polytopes for the alternating groups. Study an energy concept in graphs that was built on the combinatorial Perron value for trees, and analyse spectra of so-called bottleneck matrices of rooted trees. Investigate new concepts in the area of spectral partitioning, which has significant importance in graph partitioning/classification, and study weighted circulant matrices. Participate in transversal education projects, possibly using optimization and graphs. Improve the website for statistics students: http://sweet.ua.pt/pedrocruz/bioestatistica/. Study uniform duality for problems of conic copositive optimization. Apply methods of semi-infinite programming for solving the aircraft deconfliction problem via subliminal speed regulation. Investigate distribution robust optimization problems. Complete the characterization of integer eigenvalues (and respective multiplicities) of the n-Queens graph. Investigate several families of integer graphs. Continue investigation of lexicographic products of graphs whose main eigenvalues remain the same as those of the components, and provide spectral characterization of isomorphic graphs. Investigate the spectral properties of graphs with a dominating induced matching (DIM) as well as their recognition in families of graphs with particular (k,\tau)-regular sets. Continue studying of the concepts and practices of mathematics teachers and future teachers in respect with the use of the history of mathematics in the classroom, with producing some materials. Continue studying singular differential geometric structures (Hodge theory and heat kernels for almost-Riemannian manifolds) and develop models for virtual economies. Study in detail the dynamics of billiard in a rotating half-plane, and investigate the problem of optimal camouflaging with the use of the theory of vectorvalued optimal mass transfer.

Artigos em revistas internacionais -- 7 Comunicações em encontros científicos internacionais -- 5 Comunicações em encontros científicos nacionais -- 2 Teses de Mestrado - 10

Probability and Statistics' group (PSG)

(A) 2022 ANNUAL REPORT:

(1) The research realized by PSG in 2022 involved the following findings and expansions:

Limiting behavior of the maximum of a bivariate INMA model; Analysis of time series and regression modeling with maximum entropy estimation, including variable selection with normalized entropy; Bayesian proposal for modelling limited dependent data in dynamic regression models for multivariate Gaussian time series under censoring; More general, analysis of time series of counts under censoring and analysis of time series by state space models; Change point detection under state space modeling; Outlier detection and robust estimation; Intensity dependent point processes; Statistical methods in medical research; Data analysis with applications in several fields (Health Sciences, Industrial problems, Mathematics Education, Marketing).

(2) Indicators concluded in 2022:

-PhD thesis supervised by members of PSG: 1

-Master dissertations supervised/co-supervised by members of PSG: 22

-Publications (international or national journals, book chapters, proceedings): 46

-Oral communications in international and national conferences: 23 + 6

-Poster communications in international and national conferences: 1 + 14

-Seminars or palestras given by members of PSG: 4

(3) The following events were organized in 2022:

- X Workshop of Probability and Statistics group Interdisciplinarity and applications —, Universidade de Aveiro, 25/May/2022, Aveiro, Portugal
- IV Workshop in BioMathematics, 7/December/2022, Aveiro-Portugal
- Statistics on health decision making: real world data, 20-21/July2022, Aveiro- Portugal
- Probability and Statistics Group's Seminars, Aveiro, Portugal (during 2022)

(4) Visitors/Visits in 2022:

Number of researchers who visited CIDMA to work with members of PSG: 2

Members of PSG who visited foreign institutions: 3

(5) Others relevant activities in 2022:

Edition of the Journal of Statistics on Heath Decision (<u>https://proa.ua.pt/index.php/jshd/about</u>)

(B) PLAN OF ACTIVITIES EXPECTED TO 2023:

(1) In 2023 the following expansions are expected (mostly, it corresponds to ongoing research works):

Analysis of time series and regression modeling with maximum entropy estimation, including variable selection with normalized entropy; Bayesian proposal for modelling limited dependent data in dynamic regression models for multivariate Gaussian time series under censoring; Analysis of time series of counts under censoring and analysis of time series by state space models; Multivariate statistical techniques for exploit time series; Modelling data with preferential sampling; Outliers and robust estimation; Statistical methods in medical research; Continuous improvement of logistics processes in industrial contexts; Data analysis with applications in several fields (Health Sciences, Environment, Genomics, Mathematics Education, Marketing).

(2) Indicators expected to 2023:

-PhD thesis supervised by members of PSG: 3

-Master dissertations supervised/co-supervised by members of PSG: 33

-Publications (international or national journals, book chapters, proceedings): 30

-Participation in international and national conferences: 18 + 17

-Seminars or palestras given by members of PSG: 5

(3) The following events are expected to be held in 2023:

- XI Workshop of Probability and Statistics group Interdisciplinarity and applications —, Universidade de Aveiro
- V Workshop in BioMathematics
- Statistics on health decision making: real world data, 1-2/June, Aveiro- Portugal
- 5th Workshop on Maximum Entropy and its Applications
- Probability and Statistics Group's Seminars, Aveiro, Portugal (during 2023)

(4) Visitors/Visits in 2023:

Number of researchers who visited CIDMA to work with members of PSG: 1

Members of PSG who visited foreign institutions: 2

(5) Others relevant activities in 2023:

Edition of the Journal of Statistics on Heath Decision (<u>https://proa.ua.pt/index.php/jshd/about</u>)

CIDMA

Systems and Control Group

Activity Report 2022

31 December 2022

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1 Introduction

The main goal of the group is to carry out research in theoretical and practical aspects in the area of systems and control, namely in calculus of variations, fractional calculus, optimal control and its applications to epidemiological models, and behavioral systems and convolutional codes.

In 2022, the Systems and Control Group (SCG) consisted of 17 Senior Researches, 6 PhD students and 13 collaborators. During this year, the members of the group were very productive having published 1 book, 61 papers in international journals, conference papers and book chapters, and have presented 35 talks in international conferences. Moreover, the SCG supervised 4 doctoral theses and 5 master's dissertations.

2 Summary of the scientific results obtained in 2022

Below are some of the scientific results obtained within the Systems and Control group in 2022:

- New mathematical epidemic models with control strategies for HIV, Cholera, Heroin, and COVID-19, proving existence of optimal controls and developing appropriate sets of necessary optimality conditions. New controllability, stability and optimality results for fractional-order control systems.
- Mathematical analysis of hybrid models and analysis of the impacts of individual behaviors on the spreading of an epidemic. Mathematical analysis of complex networks of epidemic models and of complex networks with non-identical predator-prey systems. Stability and optimal control of a delayed epidemiological models.
- Dynamical behavior of the SIR endemic model for childhood infectious diseases in absence of vaccination campaigns. Namely, it was considered a population that is not isolated and has interactions with the rest of the world in form of infections due the interplay with other population outside of the mainland and also it was included in our model the fast oscillations of the contact rate due to weekly changes in the contact rates. The results show that the oscillations in the contact rate have a strong impact on the richness of the dynamics and that should not be neglected in the process of modelling the transmission of contagious diseases. Furthermore, the amplitude of the oscillations has a strong influence on the transition from chaotic dynamics to regular dynamics.
- Problems of the calculus of variations, when in presence of different types of fractional derivatives, were considered. Namely, for tempered fractional derivatives, for distributed order fractional derivatives, and derivatives

with respect to another function. The fundamental problem was addressed, obtaining the Euler-Lagrange equation, and for variational problems with additional restrictions on the problem. A numerical method, based on an expansion formula involving integer-order derivatives, was also considered.

- Necessary optimality conditions for (classical) variational problems of Herglotz for the case where the Lagrangian depends not only on the independent variable, an unknown function x and its derivative and an unknown functional z, but also on the end points conditions and a real parameter.
- Necessary optimality conditions for Herglotz-type variational problems dealing with fractional derivatives of distributed-order with respect to another function (with and without time delay, with higher-order derivatives and with several independent variables).
- Patients with diabetes on an intensive insulin regimen need, in addition to basal insulin, a bolus of prandial insulin to compensate for the carbohydrates (CHO) ingested at meals. However, estimating the amount of CHO in a meal is a complex and error-prone task, becoming a significant cause of uncertainty in the optimal bolus calculation. In addition to the difficulty of estimating the carbohydrates consumed, other individual lifestyle factors can affect blood glucose levels, such as physical activity and stress. Consequently, an inadequate prandial insulin bolus may lead blood glucose levels out of the safe range, triggering hypoglycemia or hyperglycemia events. In order to minimize the impact of these errors, bolus optimization models were developed with the aid of mathematical methods and also with artificial intelligence that has been widely used in the health field.
- Results in the area of convolutional codes, namely, in periodic convolutional codes, where two types of state space realizations of these codes were defined and studied. State space realizations of convolutional codes over finite rings were also studied and a construction of optimal convolutional code for decoding over the erasure channel was obtained.
- Characterization of the set of feasible initial conditions on a diagonal line in order to compute the solutions of a 2D discrete state-space system on a half-plane of the 2D grid. Characterization of the trim subspace of a statespace system. Method for obtaining a minimal state-space realization of an input-output behavior, starting from a non-minimal realization of this behavior.
- Models for predicting how much a consumer is willing to pay for a bottle of wine, given information such as his/her gender and age: less than EUR 2.99; between EUR 3 and 4.99; between EUR 5 and 9.99; EUR 10 or more. Since these intervals can be viewed as ordered classes, the prediction problem was treated as a multi-class ordinal classification task. Several types of

predictive models were considered, namely decision trees, artificial neural networks and support vector machines, and learning methods, such as the unimodal learning paradigm. We had to cope with the imbalancement of the training set and, in this context, we applied several re-sampling methods, like the synthetic minority over-sampling technique.

3 List of Publications 2022

3.1 Books

 P. Agarwal, J. J. Nieto and D. F. M. Torres, Mathematical Analysis of Infectious Diseases, Academic Press, London, UK, (2022). http://dx.doi.org/10.1016/C2020-0-03443-2

3.2 Publications in International Peer Review Journals

 C. Abreu, D. Amorim, and F. Miranda, Personalized limits to carbohydrate counting errors: A data-driven approach, ATTD Advanced Technologies & Treatments for Diabetes Conference, Barcelona, Spain, April 27-30, 2022, Diabetes Technology & Therapeutics, Vol. 24 (2022), no. S2, p. A-6.

https://doi.org/10.1089/dia.2022.2527.abstracts

- K. Allali, S. Harroudi and D. F. M. Torres, Optimal control of an HIV model with a trilinear antibody growth function, Discrete Contin. Dyn. Syst. Ser. S 15 (2022), no. 3, 501–518. https://dx.doi.org/10.3934/dcdss.2021148
- R. Almeida e M. L. Morgado, Optimality conditions involving the Mittag– Leffler tempered fractional derivative. Discrete Contin. Dyn. Syst. Ser. B 15 (2022), no 3, 519–534. https://dx.doi.org/10.3934/dcdss.2021149
- 4. R. Almeida, R. Agarwal, S. Hristova e D. O'Regan, Stability of gene regulatory networks modeled by generalized proportional Caputo fractional differential equations. Entropy 24 (2022), no 3, 372. https://dx.doi.org/10.3390/e24030372
- R. Almeida, Minimization problems for functionals depending on generalized proportional fractional derivatives. Fractal Fract. 6 (2022), no 7, 356. https://dx.doi.org/10.3390/fractalfract6070356
- R. Almeida, Variational problems of variable fractional order involving arbitrary kernels. AIMS Mathematics 7 (2022), no 10, 18690-18707. https://dx.doi.org/10.3934/math.20221028

 H. Alonso and T. Candeias, Predicting how much a consumer is willing to pay for a bottle of wine: a preliminary study. Procedia Computer Science 204 (2022), 836-843. https://dx.doi.org/10.1016/j.procs.2022.08.101

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- G. Cantin, C. J. Silva and A. Banos, Mathematical analysis of a hybrid model: Impacts of individual behaviors on the spreading of an epidemic. Networks and Heterogeneous Media, Vol. 17 (2022), no. 3, 333-357. https://doi.org/10.3934/nhm.2022010
- A. Chidouh, R. Atmania and D. F. M. Torres, Study of a Fractional Creep Problem with Multiple Delays in Terms of Boltzmann's Superposition Principle, Fractal Fract. 6 (2022), no. 8, Art. 434, 11 pp. https://doi.org/10.3390/fractalfract6080434
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- L. Michel, C. J. Silva and D. F. M. Torres, Model-free based control of a HIV/AIDS prevention model, Math. Biosci. Eng. 19 (2022), no. 1, 759-774. https://dx.doi.org/10.3934/mbe.2022034

D. Napp, R. Pinto and C. Rocha, State representations of convolutional codes over a finite ring, Linear Algebra and Its Applications 640 (2022), 48-66.

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- 33. C. J. Silva, G. Cantin, C. Cruz, R. Fonseca-Pinto, R. P. da Fonseca, E. S. dos Santos and D. F. M. Torres, Complex network model for COVID-19: human behavior, pseudo-periodic solutions and multiple epidemic waves, J. Math. Anal. Appl. 514 (2022), no. 2, Art. 125171, 25 pp. https://dx.doi.org/10.1016/j.jmaa.2021.125171
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3.3 Chapters in Books

 A. Boukhouima, H. Zine, E. M. Lotfi, M. Mahrouf, D. F. M. Torres and N. Yousfi, Lyapunov Functions and Stability Analysis of Fractional-Order Systems, in: Mathematical Analysis of Infectious Diseases, Academic Press (2022), 125-136.
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- R. Pereira and P. Rocha, Feasible initial conditions for 2D discrete statespace systems. IFAC Papers Online, 55 (2022), no. 30, 127-131. https://doi.org/10.1016/j.ifacol.2022.11.040
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- N.R.O. Bastos, Use of Desmos to engage students in calculus, EDULEARN22 Proceedings (2022), 7766-7771. https://dx.doi.org/10.21125/edulearn.2022.1812
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- D. Miranda, R. Gonçalves, F. Veloso, F. Miranda, J. Vilaça, C. M. Costa, and S. Lanceros-Méndez, Lattice microstructure design for cathode electrodes for high-performance lithium-ion batteries, AIP Conference Proceedings (2022), 2425, 200006. https://doi.org/10.1063/5.0081322

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- 9. J. Nunes, A. Hall, and P. Vettori, Antisymmetry in Portuguese Ceramic Tile Facades, proceedings of "Symmetry: Art and Science - 12th SIS-Symmetry Congress" (2022), 34-39. https://dx.doi.org/10.24840/1447-607X/2022/12-03-034
- P. Rita, N. R. O. Bastos and A. Hall, Exploring Symmetry Through Portuguese Tiles in Historical Monuments, Proceedings of Bridges 2022: Mathematics, Art, Music, Architecture, Culture (2022) 395-398.
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- V. Santos, N.R.O. Bastos, Activities with Desmos and GeoGebra for formative and automatic feedback, EDULEARN22 Proceedings (2022), 7555-7559.

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13. F. Veloso, D. Miranda, P. Morais, H. R. Torres, R. Laranjeira, M. Ruediger, F. Miranda, A. C. M. Pinho, and J. L. Vilaça, Structural mechanical simulation to optimize the sensor arm geometry to be implemented on cranial remodeling orthosis, AIP Conference Proceedings (2022), 2425, 200004.

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3.5 Editorial work

 N. Martins, R. Almeida, C. J. Soares da Silva and M. R. Sidi Ammi. Special Issue "Calculus of Variations, Optimal Control, and Mathematical Biology: A Themed Issue Dedicated to Professor Delfim F. M. Torres on the Occasion of His 50th Birthday, Fractal and Fractional, MDPI, 2022.

3.6 Other

 C. Choquet, M. R. Sidi Ammi, M. Tilioua and D. F. M. Torres, Preface, Discrete Contin. Dyn. Syst. Ser. S 15 (2022), no. 3, i–ii. http://dx.doi.org/10.3934/dcdss.2022015

4 List of Communications 2022

4.1 Plenary/Keynote Speaker

- D. F. M. Torres, Invited Keynote Speaker, Calculus of Variations and Optimal Control with Fractional-Order Derivatives, Recent Advances in Analysis and Applications – RA3 2022 (RAAA2022), United Arab Emirates University (UAEU), Al Ain, Abu Dhabi October 19-20, 2022.
- D. F. M. Torres, Plenary Speaker of 8th IMM, Calculus of Variations with Fractional Derivatives, 8th Iberian Mathematical Meeting, organized by the Real Sociedad Matemática Española and the Sociedade Portuguesa de Matemática, Institute of Mathematics of the University of Seville (IMUS), Sevilla, Spain, October 5-7, 2022.
- 3. D. F. M. Torres, Plenary Speaker, Existence and uniqueness of solution for fractional differential equations with integral boundary conditions and the Adomian Decomposition Method, The International Conference on Mathematical Analysis and Applications in Science and Engineering (IC-MASC'2022), Porto, Portugal, June 27-29, 2022.
- D. F. M. Torres, Plenary Speaker, Controlo Ótimo e Modelação Matemática de Doenças Transmissíveis, Encontro Nacional de Estudantes de Matemática (ENEMath²²), University of Coimbra, April 9-12, 2022.
- D. F. M. Torres, Optimal Control of Distributed-Order Fractional Systems, II Brazilian Symposium of Fractional Calculus (BSFC 2022), Campinas, Brazil, January 17-21, 2022.

4.2 Invited Speaker

- R. Almeida, Calculus of variation problems for variable order general fractional calculus, 8th Iberian Mathematical Meeting (8IMM), Institute of Mathematics of the University of Seville, Spain, October 5-7, 2022.
- N. Martins, Variational principle of Herglotz for a new class of problems with dependence on the free endpoint conditions and a real parameter, 8th Iberian Mathematical Meeting (8IMM), Institute of Mathematics of the University of Seville, Spain, October 5-7, 2022.
- R. Pinto, Maximum Rank Distance Convolutional Codes, 8th Iberian Mathematical Meeting (8IMM), Institute of Mathematics of the University of Seville, Spain, October 5-7, 2022.

4.3 Contributed Talks at International Conferences

1. C. Abreu, D. Amorim, and F. Miranda, Personalized Limits to Carbohydrate Counting Errors: A Data-Driven Approach, Poster in the ATTD Advanced Technologies & Treatments for Diabetes Conference, Barcelona, Spain, April 27-30, 2022.

- R. Almeida, Variational problems of variable fractional order involving arbitrary kernels, 20th International Conference Of Numerical Analysis And Applied Mathematics (ICNAAM 2022), Crete, Greece, September 19-25, 2022.
- 3. R. Almeida, Optimization conditions for functionals dealing with variable order fractional derivatives and with dependence on an arbitrary function, The International Conference on Optimization and Decision Science (ODS 2022), Florence, Italy, 30 August-2 September, 2022.
- 4. H. Alonso, Predicting how much a consumer is willing to pay for a bottle of wine: a preliminary study.", International Conference on Industry Sciences and Computer Sciences Innovation 2022 edition (ISCSI 2022), Vila Nova de Gaia, Portugal, March 9-11, 2022.
- 5. N.R.O. Bastos, Breakout rooms: a collaborative space that works, ED-ULEARN22 Conference, Palma, Spain, July 4-6, 2022.
- N.R.O. Bastos, Use of Desmos to engage students in calculus, EDULEARN22 Conference, Palma, Spain, July 4-6, 2022.
- N.R.O. Bastos, Interlacing Islamic Art with the Teaching of Symmetry in Portuguese Schools, Symmetry Art and Science: 12th Symmetry Congress, Faculty of Architecture of the University of Porto, Portugal, July 11-16, 2022.
- N.R.O. Bastos, Exploring symmetry through Portuguese tiles in historical monuments, Bridges Aalto 2022, Aalto University, Helsinki and Espoo, Finland, August 1-5, 2022.
- 9. N.R.O. Bastos, Estratégias para envolver ativamente os estudantes no processo de aprendizagem, Encontro de Práticas de Promoção da Aprendizagem Ativa (e mais!) no Ensino Superior, Online, April 1, 2022.
- A. M. C. Brito da Cruz, Assessing multiple personal protections for Dengue: an optimal control approach, 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2022), Crete, Greece, September 19-25, 2022
- N. Martins, Generalized Herglotz-type variational problems involving distributed-order fractional derivatives with arbitrary smooth kernels, 20th Internacional Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2022), Crete, Greece, September 19-25, 2022.
- F. Miranda, Personalized and Context-Aware Decision Support System for Diabetes Therapeutics, 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2022), Crete, Greece, September 19-25, 2022.

- F. Miranda, Theoretical Simulation of Solid Polymer Electrolyte Based on Poly(vinylidene fluoride) with Lithium Salts for Lithium-Ion Battery Application, 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2022), Crete, Greece, September 19-25, 2022.
- F. Miranda, The Importance of Artificial Intelligence in Postprandial Blood Glucose Prediction for Insulin Bolus Calculation, 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2022), Crete, Greece, September 19-25, 2022.
- D. Napp, R. Pinto, and C. Vela, On rank metric convolutional codes and concatenated codes, 25th International Symposium on Mathematical Theory of Networks and Systems (MTNS2022), University of Bayreuth, Germany, September 12-16, 2022.
- R. Pereira, P. Rocha, Feasible initial conditions for 2D discrete state-space systems, 9th International Conference on Matrix Analysis and Applications (ICMAA 2022), Aveiro, June 15-17, 2022.
- R. Pereira, P. Rocha, A new insight on state-trimness and minimal statespace realizations of input-output behaviors, 15th Portuguese Conference on Automatic Control (Controlo 2022), Nova University, Lisbon, July 6-8, 2022.
- R. Pereira, P. Rocha, Feasible initial conditions for 2D discrete statespace systems, 25th International Symposium on Mathematical Theory of Networks and Systems (MTNS2022), University of Bayreuth, Germany, September 12-16, 2022.
- R. Pinto and R. Simões, Constructions of optimal 2D convolutional codes for burst decoding over the erasure channel, 9th International Conference on Matrix Analysis and Applications (ICMAA 2022), Aveiro, June 15-17, 2022.
- D. Napp, R. Pereira, R. Pinto and P. Rocha, State Space Realizations of Periodic Convolutional Code, Coding Theory and Cryptography: a conference in honor of Joachim Rosenthal's 60th birthday, Zurich, Switzerland, July 11-15, 2022.
- C. J. Silva, Impacts of individual behaviors on the spreading of an epidemic via hybrid models, Encontro Nacional da Sociedade Portuguesa de Matemática 2022 (ENSPM2022), Polytechnic Institute of Tomar, Tomar, Portugal, July 18-20, 2022.
- 22. C. J. Silva, Mathematical modeling of epidemics: ODE's, complex networks hybrid models, III Portuguese Meeting on Biomathematics (3EPB), NOVA School of Science & Technology, NOVA University of Lisbon, Caparica, Portugal, July 13-14, 2022.

- C. J. Silva, Stability of epidemic fractional models, International Conference on Mathematical Analysis and Applications in Science and Engineering - ICMA2SC'22, ISEP, Porto, Portugal, June 27-29, 2022.
- 24. C. J. Silva, Stability of fractional epidemic models, talk in "Workshop on Fractional Differential Equations and Diffusion in Complex media", La Rochelle Université, La Rochelle, France, May 18-20, 2022.
- 25. C. J. Silva, Optimal control of predator-prey systems complex network, talk in Mini-symposium "Geometric control, optimal feedback stabilization and applications", organized by Jérémy Rouot (Univ. Brest, France) and Cristiana J. Silva (Univ. Aveiro, Portugal), FGP2022-French German Portuguese 2022 Optimization conference, University of Porto, Porto, Portugal, May 3-6, 2022.
- D. F. M. Torres, Fractional Differential Equations with Integral Boundary Conditions, Joint Meeting Brazil-Portugal, Bahia, Salvador, Brazil, August 14-20, 2022.
- D. F. M. Torres, Non-Newtonian Noether's Symmetry Theorem, PACOM 2022: Pan African Congress of Mathematicians 2022, Kintele University, Brazzaville, Congo, August 1-6, 2022

4.4 Seminars

- A. M. C. Brito da Cruz, Optimal control applied to dengue disease prevention: economic burden and role of communication" in the scope of the Seminars of Systems and Control Group of the Center for Research and Development in Mathematics and Applications (CIDMA), University of Aveiro, Portugal, February 9, 2022.
- C. J. Silva, Complex networks and hybrid models applied to epidemics, Laboratoire des Sciences du Numérique de Nantes, Nantes Université, Nantes, France, April 7, 2022.
- 3. D. F. M. Torres, Fractional Differential Equations with Integral Boundary Conditions, University of Cape Verde, December 1, 2022.
- D. F. M. Torres, Parameter estimation, sensitivity analysis and optimal control of an epidemic model with application to HRSV, Think Tank UA– Pfizer, University of Aveiro (UA), November 28, 2022.

5 PhD theses defended in 2022

1. Faiçal Ndairou, Supervisor: Delfim F. M. Torres, Co-supervisor: Ivan Area (University of Vigo, Spain), Fractional optimal control and biological applications, University of Aveiro, 13 December 2022.

- Filipa Santana, Supervisor: Raquel Pinto, Co-supervisor: Diego Napp. Convolutional codes for multi-shot network coding. University of Aveiro, 27 January 2022.
- 3. Cláudia Ferreira Sebastião, Supervisor: Paulo Almeida, Co-supervisor: Diego Napp, Smaller keys for McEliece cryptosystems using convolutional encoders, University of Aveiro, 21 January 2022.
- 4. Houssine Zine, Supervisor: Delfim F. M. Torres, Stochastic Fractional Generalizations in Optimal Control, University of Aveiro, 18 July 2022.

6 MSc theses defended in 2022

- Rodrigo Miguel Cabral Bernardo, Supervisor: Marco Santos, Co-supervisor: Delfim F. M. Torres, Control method inspired by black hole dynamics, University of Aveiro, 24 November 2022.
- Benvindo Cabral Delgado, Supervisor: Delfim F. M. Torres, Cálculo das Variações Restrito e Amortecimento Fracionário, University of Cape Verde, 1 December 2022.
- 3. Vitor Manuel Sarmento Gomes, Supervisor: Paolo Vettori, À Descoberta da Matemática dos Guarda-Joias do Musa - Curvas e Superfícies, Mestrado em Matemática para Professores, 2022.
- Márcia Lemos da Silva, Supervisor: Delfim F. M. Torres, O Sistema Dinâmico de Lotka–Volterra e sua Discretização, University of Aveiro, 9 November 2022.
- 5. Willy Kevin Tafoyem, Supervisor: Paolo Vettori, Exploring decoding using machine learning, Double-Degree Master's Programme - InterMaths: Applied and Interdisciplinary Mathematics, 2022.

7 Scientific visits carried out in 2022

- 1. Cristiana J. Silva., University of Nantes, Nantes, France. Main goal of the visit: joint work with Prof. Prof. Guillaume Cantin on hybrid models and optimal control of Lotka-Volterra models applied to ecology, 4-7 April 2022.
- 2. Delfim F. M. Torres, Universidade de Cabo Verde, 29-Nov-2022 to 04-Dec-2022.
- Delfim F. M. Torres, Department of Mathematics, Moulay Ismail University, Meknes, Morocco, 13-16 October 2022.

8 Scientific visits received at DMat in 2022

- Rim Bourguiba, Laboratory of Analysis, Probability and Fractals, Department of Mathematics, Faculty of Sciences of Monastir, University of Monastir, Tunisia, 1-10 December 2022.
- 2. Ivan Carlos Area Carracedo, University of Vigo, 22-24 April 2022.
- 3. Ivan Carlos Area Carracedo, University of Vigo, 12-13 December 2022.
- Ewa Girejko, Bialystok University of Technology, Poland, 24-31 March 2022.
- Touria Karite, National School of Applied Sciences of Fez, Sidi Mohamed Ben Abdellah University, Fez, Morocco, 15-May to 12-June 2022.
- 6. Julia Lieb, University of Zurich, 16-25 November 2022.
- 7. Luís Machado, University of Trás-os-Montes and Alto Douro, Portugal, 25-30 March 2022.
- 8. Agnieszka Malinowska, Białystok University of Technology, Poland, 24-31 March 2022.
- Jaqueline Godoy Mesquita, Department of Mathematics, University of Brasília, Brasil, 24-30 March 2022.
- Juan Jose Nieto Roig, University of Santiago de Compostela, 12-13 December 2022.
- 11. Sandra Vaz, Departament of Mathematics, University of Beira Interior, Portugal, 8-9 November 2022.
- Hanaa Zitane, MACS Laboratory, Faculty of Sciences, Moulay Ismail University, Meknes, Morocco, 29-May to 1-June 2022.

9 Organization of Special Sessions in international conferences

- "Optimization and decision science: theory, numerical methods, and applications to real life", 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2022), Crete, Greece, 19–25 September 2022.
- 2. 7th Symposium on Modelling and Simulation in Computer Sciences and Engineering (MSCSE 2022), 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2022), Crete, Greece, 19–25 September 2022.

3. Symposium on Mathematical Methods for Artificial Intelligence and Its Applications (MMAIA 2022), 20th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2022), Crete, Greece, 19–25 September 2022.

10 Systems and Control Group Seminars

- 06/12/2022 Speaker: Faïçal Ndaïrou Affiliation: CIDMA, University of Aveiro Title: Fractional optimal control: theory and applications
- 06/12/2022 Speaker: Rim Bourguiba Affiliation: University of Monastir, Tunisia Title: Existence Results for Fractional Differential Equations in Presence of Upper and Lower Solutions
- 23/11/2022 Speaker: Julia Lieb Affiliation: University of Zurich Title: The relationship between non-catastrophicity and other properties of convolutional codes
- 4. 08/06/2022 Speaker: Om Kalthoum Wanassi Affiliation: CIDMA, University of Aveiro Title: My Scientific Path in Mathematics and FDEs with Integral Boundary Conditions
- 02/06/2022 Speaker: Aicha Karite Affiliation: Institute of Communications and Navigation, German Aerospace Center (DLR), Germany Title: Machine learning and urban mobility
- 6. 02/06/2022 Speaker: Touria Karite Affiliation: National School of Applied Sciences, Sidi Mohamed Ben Abdellah University, Fez, Morocco Title: Some results on regional optimal control problem for fractional systems with control delay
- 26/05/2022 Speaker: José C. Aleixo Affiliation: University of Beira Interior Title: On the state-space realization of periodic siso behaviors
- 28/03/2022 Speaker: Jaqueline Godoy Mesquita Affiliation: Department of Mathematics, University of Brasília, Brasil Title: Periodicity on isolated time scales

9. 09/02/2022 Speakers: H. Sofia Rodrigues and Miguel Brito da Cruz Affiliation: Polytechnic Institute of Viana do Castelo and Polytechnic Institute of Setúbal Title: Optimal control applied to dengue disease prevention: economic burden and role of communication

Natália Martins (Scientific Group Leader)

Ricardo Pereira (Secretary)

CIDMA

Systems and Control Group

Activity Plan 2023

31 December 2022

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1 Introduction

In 2023, the Systems and Control Group (SCG) is composed of 17 Senior Researches, 3 PhD students and 15 collaborators. It is expected that during this year, the members of the group continue to develop research in the main areas of the group, namely, calculus of variations and optimal control; coding theory, systems and control; fractional calculus and biomathematics.

In 2023, we will continue to participate in the organization of international conferences and workshops, as well as regular seminars in the Department of Mathematics of the University of Aveiro. As usual, we will be very involved in the supervision of MSc and PhD students, and postdocs. In addition, we will continue to participate in national and international conferences and collaborate with researchers worldwide.

2 Scientific plans for 2023

Below we present some of the research topics and scientific results that we intend to develop in the Systems and Control group in 2023:

- To prove necessary optimality condition for extended weighted generalized fractional optimal control problems; to investigate modified Lotka-Volterra models with different functional responses and their discretization: to study the existence and uniqueness of bounded weak solutions to nonlinear thermistor problems; to explore control methods inspired by black hole dynamics; to establish new formulas and useful properties for power fractional operators with non-local and non-singular kernels; to use integral boundary fractional models in applications; to develop stability test procedures for fractional differential equations with time delays; to provide a new perspective to the duality of fractional calculus and prove new fractional formulas of integration by parts with relevance in the calculus of variations; to study fractional operators on time scales and prove sufficient conditions for existence of a solution; to model dynamics via fractional operators and develop corresponding numerical algorithms; to investigate the regional gradient observability issue for fractional subdiffusion equations involving Caputo derivatives; to study the boundary regional controllability for a class of Riemann-Liouville fractional semilinear sub-diffusion systems with boundary Neumann conditions; to consider SICA models for HIV transmission on time scales; to study predator-prey stochastic delayed systems.
- To study variational problems and prove necessary conditions of optimality for different types of functionals involving fractional derivatives; to develop a numerical method to deal with fractional derivatives with variable order.
- To extend the theory of fractional optimal control considering dynamical systems dealing with fractional derivatives of distributed-order with respect to another function. Namely, we are interested in providing a weak

version of Pontryagin's Maximum Principle and a sufficient optimality condition under appropriate convexity assumptions.

- To study higher-order Herglotz problems (variational and optimal control approches) on Lie groups or symmetric spaces; to provide a geometric formulation of the higher-order variational problem associated to the k-harmonics curves.
- To study parametric optimal control problems, through sensitivity analysis, and their applications to the spread of infectious diseases and agricultural irrigation.
- To investigate the behavior of a Susceptible-Infected-Recovered model pertaining to chaotic attractors in terms of their spectral analysis. This approach can end up being so pertinent and insightful, in the context of universal responses of nonlinear dynamical systems under external forces.
- To obtain some good epidemiological models where it is used optimal control as a tool to predict protection strategies against diseases.
- To develop epidemiological models applying optimal control theory: the idea is to connect logistics and finance fields to optimization. With the spread of inflation, the level of spread of the prices increasing could be seen as an epidemic. Another topic of research is the use of mapping and statistical tools in the Sustainable Development Goals (SDG) context. Through indicators available in reliable databases, is expected to understand the impact of SDG in Alto Minho region.
- To construct optimal convolutional codes over a finite field and obtain a new decoding procedure over an erasure channel. To characterize the minimality of state space realizations of periodic convolutional codes
- To construct optimal rank metric convolutional codes over a finite field and to investigate the decoding of such codes over an erasure channel. To establish the fundamentals of rank metric codes over a finite ring. In particular, to present a new general encoding scheme for these codes, to establish the bounds for the sum rank distance of such codes and to construct rank metric convolutional codes over a finite ring whose sum rank distance reach the established bounds.
- To design a better ROBIN convolutional code. This is a rate-optimal code with some issues such as the field size required for its construction. In this sense, we propose a new construction that deals with this problem.
- In the literature, Rank metric, Gabidulin and convolutional codes have, in some cases, efficient decoding algorithms. These algorithms will be deeply studied in order to accomplish an effective decoding algorithm for rank metric convolutional codes over rings. We will make use of the previously designed algorithm.

- To develop and apply new methods for imbalanced learning. We also plan to study the forward propagation of error in artificial neural networks.
- Analysis and algebraic characterization of anti-symmetric friezes and patterns built with Truchet tiles.

3 Organization of scientific meetings in 2023

- 1. CIDMA meeting 2023, 9-10 January 2023.
- 18th Theory of Quantum Computation, Communication and Cryptography, University of Aveiro, 24-28 July 2023.
- 3. Systems and Control Group Workshop 2023 SC2023, September, 2023.
- 4. Regular SCG seminars (typically 1-2 per month).

4 Research Projects

 Project title: Mathematical Modeling of Multi-scale Control Systems: applications to human diseases.
Principal Researcher: Cristiana Silva Research project financed by FCT-Fundação para a Ciência e a Tecnologia (2023-2025).

5 Scientific visits to be carried out in 2023

- 1. R. Almeida. Visit to the Faculty of Computer Science at Bialystok University of Technology, Poland, to work with Agnieszka Malinowska and Ewa Girejko. April 2023.
- 2. N. Martins. Visit to the Faculty of Computer Science at Bialystok University of Technology, Poland, to work with Agnieszka Malinowska and Ewa Girejko. April 2023.
- 3. R. Pinto. Visit to the University of Zurich, June 2023.
- 4. D. F. M. Torres. Visit to the University of Mascara, Algeria.
- 5. D. F. M. Torres. Visit to the United Arab Emirates University, UAEU.

6 Scientific visits to be received at DMat in 2023

- Agnieszka Malinowska, Białystok University of Technology, Poland, 2-9 January 2023.
- 2. Ewa Girejko, Białystok University of Technology, Poland, 2-9 January 2023.
- Luís Machado, University of Trás-os-Montes and Alto Douro, Portugal, 3-6 January 2023.
- 4. Besma Fadlia, University of Constantine 1, Algeria.
- 5. Touria Karite, Sidi Mohamed Ben Abdellah University, Fez, Morocco.

Natália Martins (Scientific Group Leader)

Ricardo Pereira (Secretary)