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E.V.  
J.Z.  
M. U.  
Pablo  
M.T.  
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**External Advisory Committee**  
**Report for the Period of January 01, 2020 to**  
**December 31, 2023**

**Centro de Investigação e Desenvolvimento em**  
**Matemática e Aplicações (CIDMA) <sup>1</sup>**  
**University of Aveiro**

## 1 Introduction

CIDMA is a research centre in the Department of Mathematics (DMAT) at the University of Aveiro (UA). CIDMA has been in operation since 2010.

The current report summarizes the findings of Dam's External Advisory Committee (EAC) at its most recent meeting at UA on 8-10th May 2023. All eight committee members were in attendance in person. The report is for the period of January 2020 to present. The EAC has focussed on this period as the current funding period but notes that this report is the first formal report since October 2017. The current report is based on the Centre's FCT Reports for the years 2020 onwards, as well as on information and data made available to the Committee during the meeting in Aveiro.

The members of the EAC are:

- Miguel Anjos, University of Edinburgh, Edinburgh, Scotland
- Hans G. Feichtinger, University of Vienna, Vienna, Austria
- Peter Filzmoser, TU Wien, Vienna, Austria
- Massimo Lanza de Cristoforis, University of Padova, Padova, Italy
- Snezana Lawrence, Middlesex University, London, United Kingdom
- Pablo Pedregal, Universidade de Castilla-La Mancha, Ciudad Real, Spain
- Egon Schulte, Northeastern University, Boston, MA, United States
- Elizabeth Winstanley, University of Sheffield, Sheffield, United Kingdom

During the EAC visit presentations were given by the Vice-Rector of UA; the Director of the Department of Mathematics; the Coordinator, Vice-Coordinator and Adjunct Coordinator of CIDMA; the Coordinators of the eight research groups; the Coordinators of the Thematic Lines; and some of the leaders of

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<sup>1</sup><http://cidma.mat.ua.pt/>

individual projects. The EAC also had discussions sessions with Researchers, PostDocs and PhD students in CIDMA. Throughout the EAC visit there were ample opportunities for informal discussions with members of CIDMA. The EAC would like to thank CIDMA for their hospitality during the visit, comprehensive information provided, and helpful administrative support.

## 2 Research Groups

CIDMA is formed of eight research groups which provide a structure for its research and scientific activities. In this section, we provide an overview of each of these groups.

### 2.1 Algebra and Geometry

The Algebra and Geometry Group (AGG), led by Professor Dirk Hofman, has a strong research presence in several branches of algebra, geometry, and related fields. The researchers in this Group fall into three, partially overlapping subgroups with research broadly represented by one the following three combinations of fields, all under the common umbrella of algebra and geometry:

- Geometry, Combinatorics, and Group Theory;
- Number Theory, Coding Theory, and Algebraic Geometry; and
- Logic, Computer Science, and Categories.

These three subgroups each have three to five researchers, and are more or less coherent as evidenced by joint research projects and publications. This is in contrast to the diversity of the Group as a whole, which appears a little heterogeneous. AGG currently has 12 Members with a PhD, 4 PhD students, and 9 Collaborators. As of May 2023 the Group had produced 2 PhD students within the 2020-2023 evaluation period, and is expected to graduate one more PhD student by the end of 2023.

The Group's research activities concern topics from the following broad range of areas: the discrete geometry, group-theory, combinatorics, and topology of highly symmetric structures such as maps and hypermaps on surfaces, polyhedra, polytopes, hypertopes, graphs, and spherical tilings, as well as their symmetry groups; diophantine equations, elliptic curves, intersection curves of ellipsoids and tori, as well as related topics in number theory and algebraic geometry; category theory and its applications to problems in algebra and topology; algebraization of logics; cryptosystems, quantum convolutional codes, as well as related topics in cryptography and coding theory. This summary indicates a remarkable breadth of research topics. AGG runs a regular Seminar featuring both external and internal speakers. Because of the diverse makeup of AGG and to improve accessibility of research topics within the Group, prior to Covid, the AGG Seminar had adopted the attractive format of letting members of AGG

offer mini-courses run over three to four regular Seminar sessions. The Group is planning to revive this mini-course format for the Seminar in the near future.

AGG has been very research active, and collectively has had 40 research papers published or accepted for publication since 2020. The articles frequently appear in strong, in some cases excellent, peer-reviewed international research journals and conference proceedings, including *Advances in Mathematics*, *Journal of the European Mathematical Society*, *IEEE Transactions on Information Theory*, *Journal of Algebra*, *Annals of Combinatorics*, and *Mathematics of Computation*. The Group is also involved in several Projects.

The AGG researchers have close collaborations with researchers from other research institutions in Portugal and abroad, including distinguished researchers from Canada, Denmark, Germany, New Zealand, Spain, the United Kingdom, and the United States of America. Members of the Group have been selected to deliver invited lectures at important international conferences, workshops, and summer schools. The Group also has a strong record of involvement in the organization of conferences, workshops, and special sessions, including events at UA. Some AGG members serve on the editorial board of strong mathematics research journals such as *Ars Mathematica Contemporanea*, *Theory and Applications of Categories*, and *Categories and General Algebraic Structures with Applications*. Many members of AGG have an international reputation and are highly respected in their fields.

The Algebra and Geometry group is also the home of Geometrix, CIDMA's long-running, interactive educational project that develops and researches interactive collaborative educational software for the teaching of mathematics in schools, with a focus on geometry instruction. This project has been tremendously successful. More details are described in Section 3.2.

In summary, the Algebra and Geometry group has presented an excellent record of accomplishments for the review period 2020-2023.

## 2.2 Complex and Hypercomplex Analysis

The Complex and Hypercomplex Analysis Group (CHAG) is one of the oldest and most homogeneous groups within CIDMA. It is coordinated by Uwe Kaehler. Founded in 1999 it is one of the world-wide leading research groups in this field, with an well established international network including all the international players in this field, from Ghent to Macau, and from Freiberg or Milano to Wuhan.

During the period 2020 to 2023 the group consisted of 9 members with PhD, including 2 researchers, as well as 2 PhD students (one going for a double degree with the University of Stuttgart). Three more PhD students started their studies during this time and two more will start this year, all funded by FCT and other institutions.

The group has performed extremely well in all the categories that one can apply to a research group, namely in terms of scientific output (results and publications), recognition within the community (presentations, organisation of events, funding) or service to the community (connecting to other teams, taking

on duties as peer reviewer, international thesis evaluation, or accepting duties in scientific bodies such as ISAAC).

To be more specific let us start with the continuous involvement of the team in the organisation of not only sessions at international conferences like the ISAAC Congress, IWOTA, ILAS, ICNAAM, ICCA and several others but also in the long-term realisation of their Annual Workshop on Applications and Generalizations of Complex analysis (20th and 21st, in 2022 and 2023), paired with the 23rd and 24th European Intensive Course on Complex Analysis, its Generalizations and Applications. A distinguished feature is these regular events taking place in Aveiro every summer, now for 24 years, is the fact that international scientists share their experience with young visitors, who can participate, without having to pay a participation fee. A special involvement in the running of a network has been undertaken by Uwe Kaehler, who has been elected president of ISAAC (Int. Soc. of Analysis, its Applications, and Computation), in 2021.

The group has published 36 papers in international journals like Math. Annalen, Journal of the EMS, Journal d'Analyse Mathematique, J. Four. Anal. Appl., J. Math. Anal. Appl., Proc. Amer. Math. Soc or Inverse Problems, so it is highly visible in the relevant literature. Also two books have been edited by the team. The members were also very active in dissemination by participating in a large number of scientific events, with 50 presentations at international conferences. One may mention that P. Cerejeiras was one out of just 19 invited speakers (aside with T.Tao, M. Ruzhansky, or C.Kenig) at ICMAM2022 (on Multidisciplinary Aspects of Mathematics and its Applications) in Columbia. Also the group runs a very active policy to attract foreign collaboration partners to visit Aveiro.

Concerning the research topic and principal results one has to mention first of all the work on the Calderon problem for complex conductivity in  $2D$  and  $3D$ , based on methods from quaternionic analysis. This represents a breakthrough both from a theoretical and potentially from a practical point of view, with interesting possible applications in Electric Impedance Tomography. Competing international groups do not have such a result so far.

In the context of spectral theory for Clifford-valued operators a Grotthendieck-Lidskii formula for the eigenvalues of a quaternionic nuclear operators over locally convex spaces has been derived. Part of the approach involved the establishment of suitable adaptations of the concept of a trace and Fredholm determinants for such operators.

Another area, where the group members have demonstrated their ability to combine the development of theoretical concepts with a close view on potential applications to concrete problems is the continued study of fractional derivatives. Combined with the expertise concerning Special Functions the eigenfunctions for fractional derivatives could be derived. Based on this information a variety of applications and estimates (to Cauchy problems, harmonic analysis over hyperbolic spaces, Strichartz and dispersive estimates, to mention a few) could be derived.

The group has been also productive a number of further areas of independent interest, and has produced results on function spaces and the Fourier and related

transform, notably in the context of Morrey spaces. In a more stochastic setting appropriate spaces of stochastic distributions with applications to continuous Dirac equations have been constructed.

In addition the study of matricial orthogonal polynomials as well as Markov chains with multiple orthogonality relations has been pursued, and explicit formulas for concrete families of this form (Jacobi, Meixner, Kravchuk, Laguerre, to name a few) could be obtained.

Finally it should be mentioned that the group is about to explore the potential of the use of new activation functions for artificial neural networks in the context of structural health monitoring (SHM). This is another demonstration of the open-mindedness of the team and the willingness to engage in the often cumbersome bridging of theoretical and practical mathematical research.

In summary, CHAG is a well-performing group engaged in all aspects of scientific research, from theoretical research to real-world applications, from building an international network to support the community by taking responsibility for communication the dissemination of scientific results, and of course by publishing in high reputation journals and present the results at conferences and workshops.

### 2.3 Functional Analysis and Applications

The FAAG group is coordinated by Luis Castro (who has been Vice-Rector of the University from May 2018 to May 2022). The group has currently 10 members: 9 of them have a PhD and one of them is a PhD student, 3 are Full Professors with the Portuguese Habilitation, 2 are Associate Professors, 1 is Assistant Professor, 2 are researchers with 6-year contracts supervised by L. Castro and E. Rocha, respectively, 1 is a researcher with 3-year contract supervised by L. Castro. There is currently one PhD student, whose scholarship is funded by a project of the supervisor E. Rocha.

We also mention some external collaborators in CMA – Centro de Matemática e Aplicações, UBI, CMUC – Centro de Matemática, U. de Coimbra and UA.

The group has a very active biweekly seminar that has been running during the teaching periods for more than 20 years, one of the longest of the history of the Department.

The Group achieved a large number of excellent theoretical and application results including contributions to the areas that we list below. We emphasise that the members of the group show to master a whole range of sophisticated mathematical tools of operator theory, integral transforms, harmonic analysis and differential equations as well as topological methods for nonlinear integral and differential equations. Moreover the group has shown the ability to produce a number of outputs of clear interest in the applications and to win competitive projects for a total amount of approximately 3.2 million euros.

*Boundary Value Problems, Partial Differential Equations and Inclusions:*

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Existence, multiplicity and qualitative results for partial differential equations and inclusions involving several p-Laplacians and different types of constraints (e.g. anisotropic equations with a locally defined reaction and quasilinear parabolic equations with non-monotone multivalued terms).

Time-fractional telegraph equation of distributed order in higher dimensions, and fractional Sturm-Liouville telegraph problems. Properties of several other fractional differential equations involving Hilfer, Caputo and Riemann-Liouville fractional derivatives.

Ulam-Hyers-Rassias stabilities of classes of differential equations and boundary value problems. Mixed impedance boundary value problems for the Laplace-Beltrami equation.

*Function Spaces and related problems:*

Density results for Besov and Triebel-Lizorkin spaces on rough sets.

New vanishing subspaces of Morrey spaces. Properties of microlocal Besov-type and Triebel-Lizorkin-type spaces with variable exponents.

Novel applications of the boundary element method involving fractal sets. Study of the deformation of unit balls in Lebesgue spaces.

*Operator Theory and Integral Equations:*

New convolution type operators and equations involving different integral transforms (e.g. the offset linear canonical transform).

New properties of maximal, potential and singular type operators in Morrey spaces. Boundedness results for commutators of potential operators in vanishing Morrey spaces.

Boundedness of the Hardy-Littlewood maximal operator in variable exponent Stummel spaces.

Multidimensional time-fractional diffusion-wave operator with time-fractional derivative.

Integral equations and operators of Wiener-Hopf and Hankel type.

*Real life applications:* The group has devoted a considerable amount of work into developing algorithms and packages that are useful in the applications. In particular:

Edge-device algorithms, including (a) new multiscale algorithm for data-drift analysis, (b) development of mathematical tools for innovative optical sensors in collaboration with I3N.

Distributions, game theory and graph theory, including (a) a new degradation mode; (b) applications of GFT for root cause analysis (RCA) of hybrid systems; (c) new approaches for statistical RCA and robust machine learning approaches combined with game theory techniques applied to the ceramic industry; (d) new approach of belief propagation algorithms for RCA with applications to gas leakage problems and medical data.

Prediction and simulation, including (a) new algorithms for bottleneck identification of balanced manufacturing lines (BML); (b) simulation and prediction

of bottlenecks on BML at Bosch; (c) new approach to predict issues in highly sensitive gas leakage processes.

Benchmarking, including (a) several applications of Multidirectional Efficiency Analysis (MEA) algorithms to econometrics; (b) applications to manufacturing workers' performance.

Complete solutions deployment, including (a) four use cases on the shop floor of Bosch and OLI facilities, receiving real-time sensor data, using our algorithms, and showing results in dashboards to workers and managers; (b) creation of a physical space for process simulation of segments of BMLs (AIDI5.0).

*International cooperation:* The Group enjoys a high international reputation with collaborations with members of 23 high profile institutions world wide and several of its members are involved at a high level in international associations for Mathematics: A. Caetano is Vice-President of CIM (Centro Internacional de Matemática) and has been elected in 2022 as one of the four delegates representing the 48 institutional members of the EMS in its Council. L.P. Castro joined the pool of experts of the Institutional Evaluation Programme (IEP) of the European University Association. V. Staicu is the Interim Vice-President of the American Romanian Academy of Arts and Sciences (ARA) and a member of the Register of Expert Peer Reviewers for Italian Scientific Evaluation (REPRISE database).

*Dissemination of results:* With the pandemic crisis most of the talks and meetings have been held on line and the members of the group have delivered 4 talks in international meetings and 11 talks in national meetings in 2020, 13 talks in international meetings and 9 talks in national meetings in 2021, 28 talks in international meetings and 16 talks in national meetings in 2022.

*Editorial duties:* Members of the Group are active as members of seven Editorial Boards of international journals. Vasile Staicu is Editor in Chief of "Libertas Mathematica", which is now edited at UA.

In summary, the FAAG group has an excellent international reputation, is well connected to a considerable number of international research institutions and during the evaluation period has shown to be able to produce excellent research work that has been disseminated worldwide and has appeared in over 50 scientific publications in highly profiled scientific Journals. The FAAG has also been very active in implementing effective interdisciplinary projects for the real world and has invested a good deal of energy into services related to research for the mathematical community such as editorial duties and international research evaluations.

## 2.4 Gravitational Geometry and Dynamics Group

The vibrant and internationally-leading GGDG currently comprises 11 researchers with a PhD (two of whom are permanent researchers) and 9 PhD students. It

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is coordinated by Carlos Herdeiro. The group's research is focused on two areas: strong gravity and high-energy physics. There is considerable synergy and collaboration between the two strands, for example, members of the group have studied ultra-light bosons from the perspectives of both gravitational and particle physics. Members of GGDG collaborate widely with leading international researchers at all career stages, in Europe and beyond.

The group's research output during the period is extremely impressive, both in terms of breadth and depth of high-quality, internationally-leading, work. Over 120 publications have appeared during the review period. The research of the group covers as diverse a range of topics in mathematical physics as: boson stars, black hole perturbations, solitons in classical field theory, gravitational wave phenomenology, particle physics collider phenomenology, dark matter, classical gravitation, beyond the standard model physics, ultra-compact objects, and black hole shadows to name but a selection. The group has particular expertise in the numerical solution of both equilibrium and evolving gravitational systems, and applies this expertise to both mathematical and (astro)physical problems.

GGDG members publish in the leading international journals in the field (such as Physical Review Letters, Physical Review D, Classical and Quantum Gravity, JHEP, JCAP, etc). Particularly noteworthy are the seven papers in the top journal Physical Review Letters during the review period, and the group's contribution to the community effort in the influential Living Reviews in Relativity article "New Horizons for Fundamental Physics with LISA" (2022). Publications produced by GGDG in the review period have been highly cited, continuing the group's extensive track record of high-impact research.

Looking ahead, the group is well-placed to capitalize on the plethora of new observational data expected in the coming years, particularly (but not exclusively) from gravitational waves, as well as computational innovations such as the application of deep learning and machine learning techniques. The group is very active already in these areas. It is good to see membership of strategically important major international collaborations such as the LISA consortium.

Energetic leadership is provided by Carlos Herdeiro, with the welcome recent addition of Eugen Radu to the permanent research staff. There is an impressive track record of external grant awards, primarily from FCT, but also a significant EU networking grant, led by GGDG (see Section 4.2). The number of researchers supported by longer-term CEEC fellowships is also very impressive. PhD students in the group are funded by a mixture of FCT scholarships, grants awarded to GGDG and some self-funding students. GGDG has a strong track record of PhD student supervision, with recent PhD graduates successful in obtaining post-doctoral positions at leading international groups in the field.

Research in this area requires access to substantial computing resources. The group has been awarded time on the high-performance computing facilities locally in Aveiro, which provides cost-effective computing to meet the requirements of the group. There is a sensible plan in place for continuing access to the necessary computing resources.

The group has a very active programme of weekly seminars and journal club



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gatherings, and a steady stream of visitors, ranging from leading international experts in the field to junior researchers, in addition to hosting important community workshops, such as the well-established Black Holes meeting (hosted by UA in December 2021) and the forthcoming Einstein Toolkit workshop, to be held in Aveiro in June 2023. Further evidence for the international impact of GGDG’s work is provided by the group leader’s membership of the editorial board of a key journal (EPJC) in the field and the steady stream of invitations for group members to speak at prestigious institutions and conferences.

The majority of researchers within GGDG are not permanent. While the comparatively large number of researchers on 3 + 3-year contracts is to be welcomed as providing some stability (and reflects the excellence of the group members), members of the group expressed some anxiety about the longer-term academic career prospects in Portugal.

Discussions with younger researchers in the group highlighted two practical resources which it would be helpful for the institution to provide: a site license for *mathematica* and access to American Physical Society Journals (in particular Physical Review Letters and Physical Review D).

Overall, the current review period has been highly successful for GGDG, with the publication of an extensive number internationally leading research outputs; successful grant applications; and a wide range of high-quality research activities.

## 2.5 History of Mathematics and Mathematical Education

The History of Mathematics and Mathematics Education group (HMEMG) is a small but active group, and a unique such entity belonging to a funded research Centre in Portugal. Whilst there are informal groups of historians of mathematics in various universities such as Coimbra, Minho, Porto, and Lisbon, UA is the only one with a Centre that incorporates a funded research group dedicated to the History of Mathematics and Mathematics Education. The link between history and education further demarcates this group from others, and not only in Portugal but more widely, in Europe.

HMEMG has 5 Integrated members, and is led knowledgeably and confidently by Professor Helmuth Malonek. Other Integrated Members are 2 Assistant and 2 Adjunct Professors; there is 1 secondary teacher (collaborator), and 1 Phd student. 14 MSc students completed their studies in this area in 2021/22. The group has 8 international collaborators, coming from London, Berlin, Moscow, and Rio de Janeiro.

Group has a lively programme of activities, including the research seminar “Notes in the margins” held annually, and a departmental colloquium “History and Heritage of Mathematics”, which take place during international collaborators’ visits.

The group has been organising training workshops for mathematics teachers, as well as conferences in schools. Three such events were the “Histories with Science”, “Mathematics History for the Classroom”, and the conference “Stories with Science in the School Library” held in 2020, 2021, and 2022 respectively.

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HMEMG makes an important contribution to the International Study Group History and Pedagogy of Mathematics, HPM<sup>2</sup>, which is an affiliate of the International Mathematics Union. In this larger, truly global international group, the HMEMG has three members on the Advisory Board, one of whom is the co-editor of the HPM Newsletter<sup>3</sup>. This involvement is a significant contribution to the scholarship in the history and pedagogy of mathematics.

The research outcomes of this small group are considerable in the last three years: from 22 publications, there were 9 articles in peer-refereed journals, 10 chapters in books, 2 books, and 1 conference article. The publications cover a diverse range of topics from old mathematical textbooks to the role of the history of mathematics in teaching and motivation in the classroom, pedagogical quality and innovation, legacy of Portuguese mathematicians and astronomers, and creation of the historical and didactic resources for the classroom, latter covering all stages at pre-university level.

Currently, there is a huge need for a greater understanding of diversity in mathematical sciences, as well as the need for competent and high-quality outreach and expertise in dissemination of mathematical knowledge outside of strictly professional and academic audiences. This group, with the focus on history of mathematics, is inherently interested in the rich diversity of contributions to mathematical sciences from many cultures and periods. Further, history of mathematics can, and has been very successfully, used as a motivational tool in mathematics outreach. The expertise in the outreach and dissemination of complex mathematical topics to audiences beyond the professional and academic, is contained within the expertise of this research group both through its research into the history, and the didactics of mathematics.

This currently small group has a great potential to become even more valuable to the CIDMA in particular, and due to its uniqueness, to Portugal more broadly in these two contexts. The group's excellent leadership and vision should therefore be further supported by some commitment to enlarge its membership through establishing visiting professorships in the area, which can be modelled on the system already in existence, for example, in France. Although there are many such research groups and quite a few centres there, perhaps one model can be considered - the Archives Henri-Poincaré Philosophie et Recherches sur les Sciences et les Technologies at the University of Lorraine in Nancy. At this institution, every year there is a number of research professorships that contribute to boosting their research output and further collaboration with international colleagues, but also support the creation of materials for teaching at the post-graduate level and bringing innovative and new approaches into its outreach activities in mathematical sciences. The professorships are of various duration, and cater for different levels of visitors (less and more experienced), enabling a constant flow of ideas and creation of scholarship that is inspiring in its depth and width, and in interdisciplinary and international cross-fertilisation of ideas and scholarship in the history of mathematics and

<sup>2</sup><https://www.mathunion.org/icmi/organization/affiliated-organizations/hpm>

<sup>3</sup><https://groupohpm.wordpress.com/2022/11/21/hpm-newsletter-111/>

mathematics education.

In summary, it would be very beneficial to Portugal broadly, and to the University of Aveiro and CIDMA more precisely, to support this very good group further with establishing the visiting professorships in the History and Pedagogy of Mathematics.

## 2.6 Optimization, Graph Theory and Combinatorics

The Optimization, Graph Theory and Combinatorics Group (OGTCG), led by Professor Alexander Plakhov, brings together 15 researchers with a PhD and 3 PhD students. The group's research spans a number of areas, including operations research, optimization (both continuous and discrete), computing and algorithms, financial mathematics, convex geometry, and graph theory and combinatorics, notably spectral graph theory.

This highly active group has produced more than 70 publications since the beginning of 2020, as well as 5 PhD theses and 32 Masters theses. The variety of subjects covered by the group is reflected in the variety of venues in which the outputs of their research has been published, which comprise leading journals such as *INFORMS J. on Computing*, *European J. Operational Research*, *SIAM J. Discrete Optimization*, *Linear Algebra Appl.*, *Nonlinearity*, and *Calc. Var. PDEs*.

The group's achievements cover an impressive range of areas, as can be seen from the following selection of recent research contributions: study of faithful permutation representations of groups of polytopes (polyhedral theory); mixed integer optimization models and solution algorithms for optimization under uncertainty (mathematical optimization); new index theorem for graph-parametrized optimal control problems (optimal control); characterization of natural domains for singular PDEs (differential operators); solution of an open problem from 1974 on H-joins of families of graphs (spectral graph theory), and new results on solutions to Newton's problem of minimal resistance proving a conjecture from 1993 (convex geometry).

The OGTCG has a high international profile sustained not only by its important research output but also by its regular organisation of international scientific events. In spite of the covid-19 pandemic, the group hosted or will host three such major events in three years:

**DCO 2021** The Dynamic Control and Optimization conference in February 2021 was held fully online with more than 70 participants from 19 countries. This conference was organised jointly by OGTCG and the Systems and Control Group 2.8.

**ICMAA 2022** The 9th International Conference on Matrix Analysis and Applications, postponed from 2020, was hosted by CIDMA in June 2022 with 55 participants from 12 countries.

**Optimization 2023** will be the 10th edition of a series of international conferences in optimization organized in Portugal under the auspices of APDIO



(the Portuguese Operations Research Society). The conference will take place in July 2023 and is typically attended by more than 200 researchers from around the world.

Members of OGTCG have participated in several externally funded projects at CIDMA, notably CoSysM3 on epidemiological modelling (see Section 4.3), SMART-QUAL on quality management in higher education, O3F on reduction of forest fires, and Augmanity (jointly with Bosch) on the improvement of work conditions in industry. The diversity of these projects again illustrates the range of research interests represented within OGTCG.

The overall picture of OGTCG is that of a highly active and productive group of researchers. In spite of the variety of interests in the group, the group members are involved in a variety of collaborations both within the group and with other groups within CIDMA. Moreover, they are leading the organisation of major international scientific events that raise the profile of the group and of CIDMA.

## 2.7 Probability and Statistics

This PSG group, coordinated by Adelaide Freitas, consists of 16 researchers with PhD (13 are females), 5 PhD students, and 7 collaborators. The main research achievements involve methodological contributions, and contributions to various application areas. The profile of the group is wide, including research in time series analysis, multivariate and robust statistics, methods for high-dimensional data, dimensionality reduction, sampling theory, and extreme value theory. Also the application areas are diverse, with focus on health sciences and industrial applications.

In terms of scientific publications, the group has a remarkable output, with more than 80 papers, equally distributed in methodological and applied contributions. Several of the methodological papers are published in international and well recognized journals. The high quality of the papers in applied fields is visible by the choice of the publication media, with several journals ranked Q1.

Concerning student supervision, in 2022 in total 22 MSc could be concluded, some within projects with the industry, in medicine and clinical projects, and in internships. Further, 3 PhD theses were concluded in 2022 and Jan. 2023. There are collaborations with doctoral programs also outside Aveiro.

The group organizes monthly seminars and an annual workshop with focus on interdisciplinarity and applications. Also internationally, the group is represented as co-organizer of events and with conference presentations.

The group is also very active in the mathematics and statistics education, also outside the university, with summer schools for children, professional development courses for mathematics teachers, promotion of statistics and mathematics in elementary, middle and high schools, and collaboration projects with the Portuguese Statistical Society. Although such activities are not necessarily internationally visible, they will be an important investment into the future of mathematics and statistics in Portugal.

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Overall, one of the strengths of the Probability and Statistics Group is in dissemination, and specifically in education (including pre-university level), and in collaboration with people from applied fields. The group has intensive collaborations with the health sector and with the industry, and the applied problems lead to strong methodological contributions. Also students are involved in the collaborations, allowing them to apply their theoretical knowledge to practical problem settings.

The strong links to the industry and to the health sector could be useful for joint project applications (if there are appropriate project calls) in order to finance PhD students. As students and companies are already in contact, it might even be possible to receive company support for financing PhD students. This needs a clear definition of tasks and duties, but both sides could profit.

The activities concerning internationalization could be strengthened. It was of course difficult during the pandemic to invite people, but this could be pushed in future. International guests could not just give seminar presentations, but they could give short courses for PhD students, and collaborate with joint publications. Ideally, PhD students could be sent abroad in order to be involved in other research topics. International programs could be used to finance such activities.

Collaborations with computer science could be beneficial for applications with big data. Especially in the health sector, joint research linking statistical learning methods with machine learning could bring the range of application areas to a different level. Students with appropriate programming skills could be involved in such activities. This could bring the research profile of the group closer to data science, making it even more attractive for external partners.

## 2.8 Systems and Control

The Systems and Control group **SCG** has undergone some significant changes in this new period. On the one hand, the former leader of the group, D. Torres, has become the new director of CIDMA, while N. Martins has accepted the responsibility of leading the group. In addition, R. Alneida, who is a member of the group too, is the new Assistant Coordinator. Despite all these new important roles placed on members of this group, its research activity does not seem to have suffered in the least.

The group has 18 members with a PhD degree, 3 PhD students, and 15 collaborators. It is the largest research group in CIDMA. Its strongest point about making important contributions both at the theoretical and applied levels have been kept at the same quality.

- Scientific contributions. These are organized around two axes. The first one focuses on results of an analytical or methodological nature. Members of the group have continued to make progress in the use of different fractional derivatives in the Calculus of Variations, where they are becoming an international reference. They addressed basic issues on these new frameworks, like, for instance, the Euler-Lagrange equations of optimality.

In particular, they have significantly contributed to Herglotz-type problems. The second axis revolves around applications of variational principles to realistic models, mainly of a biological nature in a broad sense: epidemic models (COVID, HIV, Cholera, SIR, diabetes, ...), predator-prey models, etc.

- Scientific publications. Figures are impressive. We are talking about 172 publications including 3 books (two published by Springer and one with Academic Press). Beyond these numbers, it is important to stress that two members of the group (D. Torres and R. Almeida) are among the top 2% cited scientists according to the Stanford World's classification for 2019, 2020, and 2021. Furthermore, two of the published papers in this period have received special international recognition as Highly Cited and Influential Papers, and Best Paper Award by Axioms 2023, respectively. These are good indications that, even if quantity is not missing in terms of number of scientific articles, quality is not being neglected.
- Research projects. This is another area where this group is excellent. There have been at least four projects running up to 2022 with a total amount close to one million euros. Another one has just started, and it will go until the end of 2026. Aside from the amount of financial resources assigned to this one (virtually the maximum possible), it is worth-while to point out that it has been one of the few proposals awarded by FCT in Mathematics in the corresponding call. More information in Section 4.3 below.
- Participation in meetings and seminars. Two international conferences have been organized by the group, both in 2021. The first at UA: Dynamic control and optimization (DCO-2021) in collaboration with OGTCG, and the second one in Cape Verde: The Cape Verde International Days on Mathematics (CVIM-2021). The members of the group have also contributed to international conferences as plenary speakers (5 in 2022), invited speakers (3 in 2022), and contributed talks (27 in 2022).
- PhD thesis and students. Four doctoral theses have been defended at UA, and another four have been co-supervised by members of the group in other institutions.
- Other merits are well-represented too in the activity of the group, like international visits, seminars at international institutions, organization of special sessions in conferences, visits received at CIDMA, master theses defended, etc.

Though there may not seem to be much place for improvement, given the tremendous activity performed during the period 2020-2023, the impression of the committee is that the expertise of the group in control and optimal control guarantees the potential for further application and collaboration with control experts on the Engineering side can be of great relevance (automatic control,

robotics, ...). It is true that this task will most probably not furnish new challenges of an analytical nature, but such interaction might be of tremendous impact for Engineering. In particular, it could be a good way to provide some reinforcement to the Thematic Line Mathematics for Industry. Eventually, an industrial PhD thesis could be the outcome of such interaction. The group is more than well qualified to co-advise candidates with a clear orientation towards Industry.

### 3 Thematic Lines

The activities of CIDMA are further structured by thematic lines that provide transversal collaborations across the themes. These thematic lines provide the opportunity for members and collaborators of CIDMA to join forces on challenges that are best addressed through cross-group approaches.

The six thematic lines were presented to EAC by the corresponding coordinators.

#### 3.1 BIOMATH

This thematic line in Biomathematics, coordinated by Vera Afreixo, consists of 20 researchers from 4 different research groups of CIDMA. The topics covered include biostatistics, graph theory, optimization, dynamic systems, and mathematical modeling. The focus is on applications in health decision making, biology and precision medicine. There are various collaborations with official institutions, including the national health institution. An important challenge in such collaborations are data privacy and data protection issues. During the period 2020-2023, a total of 21 research grants have been provided, and the results have been presented and discussed in annual workshops. The results could be disseminated in several joint publications in journals and proceedings, as well as in conference presentations.

Overall, this thematic line is a very successful joint activity, with relevant contributions such as modeling data from COVID-19. In future, it could be interesting to also collaborate with other areas, such as bioinformatics, which would give plenty of opportunities for new methodological approaches.

#### 3.2 GEOMETRIX

This thematic line is coordinated by Ana Breda and has shown a great diversity of projects. Originally GEOMETRIX was starting as a software project for the illustration of geometrical properties and constructions. In the last years it seems that it has developed into two important directions.

On one hand, the illustration and extension of geometric constructions has been widened by starting a close cooperation with the GEOGEBRA community. New building blocks have been added and algorithms for the computation of the intersection curves of quadratic surfaces with a torus have been implemented.

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Thus GEOGEBRA has been expanded in this direction. On the other hand, the visual inspection of possible curves and their dependence on the used parameters are now possible, thus adding to the improvement of the understanding of 3D scenes, as is required not only in mathematics but also in architecture, for example.

The other direction pursued by this thematic line and realised in different projects is the development of software to help autistic children (in the LEMA project) respectively to identify and address the needs of the Portuguese Community of Vision Impaired in the VIAids project.

### 3.3 MATEAS

The Mathematics Teaching and Assessment in Higher Education line is coordinated by Luís Descalço and is concerned with aspects of teaching and assessment of mathematics in higher education. The 14 teachers, four students and two senior technicians involved in MATEAS focus on two main projects: SIACUA and TAMAT. Both projects concern computer-based systems for learning mathematics. SIACUA incorporates thousands of questions aimed at Calculus and Pre-Calculus students; while TAMAT involves parameterized questions of several kinds. Both systems are under active development, with resources aimed at both students and tutors and compatibility with other online systems such moodle. The resources have been evaluated using usage data and student feedback. The EAC also learned about a new project in this thematic line, PreCalculo, building on technology developed in SIACUA and working in collaboration with the Programa Operacional Capital Humano. This is an active thematic line aimed at producing high quality materials to aid the preparation of student users from diverse backgrounds for the mathematics they require for science and engineering degrees, as well as enabling student members of the thematic line to engage with valuable projects which develop transferable skills for their own career development.

### 3.4 PICS

This thematic line on Inverse Problems in Health Sciences is coordinated by Paula Cerejeiras and collaborates with several institutions in the health sector, including international partners such as an excellence group on Inverse Problems from the University of Helsinki. The research links mathematical developments with methods from machine learning and deep learning. Within different projects, PhD and MSc students are involved, and the outcome of their research is disseminated in scientific publications, and in presentations at international conferences.

These activities are another showcase for the efforts of the CHAG to infer from expertise in purely mathematical areas to potential applications to real world problems. By moving on to a computational setting the chances to go beyond speculative insight are in fact very much strengthened.



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### 3.5 MI

Mathematics for the Industry, coordinated by Rui Borges, is a thematic line that focuses on networking activities with industry and the development of new industrial collaborations. As such it maintains close connections to national and international networks to the industry, and it submits proposals in response to specific solicitations from industry. Two major industrial projects were funded via such responses: SCALUM on optimizing transportation and storage of luggage, and NEXUS on smart gates and mobility management in the port of Sines (the largest port in Portugal). There are 10 researchers from 2 research groups involved, and their scientific outcome is remarkable: supervision of 29 MSc theses, 1 PhD thesis, 12 articles in journals, 10 presentations at conferences. This line is clearly successful and the EAC believes that it has plenty of future potential (see our recommendations in Section 5.5).

### 3.6 TFC

The thematic line entitled “From Theory to Computational Frameworks” and coordinated by Eugénio Rocha follows the idea to implement theoretical findings in software and ensure that it is made available in a form which is ready for use. There is even a whole scheme behind it, developed by Rocha, that allows to adapt the different modules to new configurations by taking changes in the model parameters into account. These provisions make it possible to rapidly obtain suitable code even under constantly changing environment, as is often the case in industry. This increased flexibility and ability to react on upcoming variations can be a big advantage compared to research and software teams elsewhere.

Furthermore, interdisciplinary projects, jointly with other institutes from UA, are defined and carried out with industry partners such as Bosch-Aveiro, in the framework of MSc theses and in the preparation of several packages for the application of theoretical results to real-world problems. This creates strong partnerships with industry where both sides profit: the university with new challenging problem settings, and the industry partner with innovative solutions. It provides the students involved with a unique double qualification, as they are receiving an academic degree at the same time that they gain experience in the realization of applied projects, with industrial partners, and real deadlines.

This thematic line has great potential for further expansion given the infrastructure built up so far. However, it needs extra administrative support to fully develop its potential. One may even hope that the research carried out in this context could lead to the creation of some start-up companies, if suitable support is provided by the university or appropriate funding agencies.

## 4 Externally Funded Research Projects

CIDMA members have been successful in raising research support beyond the centre’s base and programmatic funding through grants obtained for specific

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projects. The following projects were presented to EAC by their PIs.

#### 4.1 Hypergeometric Functions and Machine Learning in the Diagnosis Process

This project was funded through a special call issued by FCT in collaboration with Google. It supports the access to large-capacity computing environments for simulations with activation functions in fractional neural networks, with applications to medical image processing. The time-frame of this ongoing project is one year, and an extension would be highly desirable.

#### 4.2 Projects in Gravitational Geometry and Dynamics

The GGDG has a sustained track record of successful grant applications to FCT and EU programmes. The group coordinator highlighted three recent projects:

- EU Horizon Europe MSCA Staff Exchange project on “Fundamental fields and compact objects: new opportunities”. This four-year project builds on three highly successful previous MSCA networks, and funds staff exchanges, schools, conferences and workshops.
- FCT-CERN project on “Gravitational waves and black holes as ultra-light dark matter particle detectors”, a two-year project following-on from previous FCT-CERN projects.
- FCT-funded project “Testing the Kerr hypothesis with gravitational waves and lensing”, a three-year project awarded in the highly-competitive annual contest.

It is notable that these projects build on previous successes of the GGDG, and demonstrate the overall strategic plan of that group to link theoretical mathematical developments, new computational methodologies and observational consequences. Support provided by UA for project applications, particularly to EU programmes, was greatly appreciated by the GGDG coordinator, and contributed to the success of the above applications.

#### 4.3 Covid-19 and CoSysM3 Projects

Under the leadership of Professor Cristiana Silva, two projects on mathematical modelling for epidemiology have recently been funded at CIDMA. The first project was funded through the rapid call from FCT at the onset of the Covid-19 pandemic in early 2020. It was concerned with developing a systemic strategy for community health intervention in the context of the pandemic, and carried out with participation of several CIDMA collaborators and of the local Public Health Unit (Unidade de saúde pública do Pinhal Litoral). While this was a small project, it is noteworthy that it was **the only mathematics-based project funded in this call**, with most of the other funded projects being in medical-related disciplines.

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The second project is a significantly larger FCT-funded three-year project on innovative mathematical modelling of behavioural epidemiology. This project started in March 2023 and brings together 20 researchers with a PhD from 5 institutions based in Portugal, France and Italy. The project will develop new hybrid models and optimal control approaches to achieve a deeper understanding of in-host and communicable diseases.

These two projects are clearly aligned with the thematic line BIOMATH and expand an area of multi-disciplinary research which promises to yield significant scientific contributions in the coming years.

## 5 Observations by the EAC

Thanks to the increased support by FCT via the programmatic funding, CIDMA was able to carry out its plan to double the number of thematic lines from three to six. The lines that already existed in 2016 are GEOMETRIX, MATEAS, and PICS, and the new lines created in recent years are BIOMATH, MI (Industry), and TFC. This is a positive development, with the new thematic lines already making significant progress and showing great potential for further active expansion.

All researchers and PhD students with whom the EAC interacted praised the informal research environment at CIDMA, with many comparing it very favorably to other institutions in which they had worked. The transparency of governance and decision-making within CIDMA was highly valued by younger researchers, and the Committee got the impression that CIDMA members were largely happy that resources were allocated fairly. Generally speaking the flat hierarchy within CIDMA was praised. Given the large size and diversity of CIDMA, the leadership team is to be commended on this.

The EAC also received very positive feedback on the office space, facilities and library provided in CIDMA, which facilitated opportunities for discussion both within and between research groups. The money available in CIDMA for visitors and travel, and the flexibility with which it can be spent, is highly valued by researchers and students. The administrative research support provided both within CIDMA and the wider UA was praised by CIDMA members as making an invaluable contribution to their work and successes.

In terms of PhD training, the EAC welcomes the formation of a Doctoral School at UA, particularly the potential to develop stronger links with industry in PhD programmes. The breadth of mathematical research within CIDMA was seen by PhD students as a very positive feature, as were the Thematic Lines. This breadth does present challenges in providing sufficient classes on advanced material required by students starting their PhDs. The joint PhD programme with Minho and Porto improves this situation to some extent, but the EAC wonders whether there might be further scope for wider collaboration between institutions in Portugal to provide graduate courses, perhaps using video conferencing technology (as has been the successful model in the United Kingdom for over a decade) or setting up a central delivery model as is done for

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operational research by NATCOR <sup>4</sup> in the UK and LNMN <sup>5</sup> in the Netherlands.

While CIDMA has successfully obtained research funding from European programs, see e.g. Section 4.2, the EAC strongly encourages CIDMA members to continue to actively seek further collaboration with European researchers to apply for support from European funds. A concrete example for obtaining extra support from European sources might be through the Marie Skłodowska-Curie Postdoctoral Fellowships (MSCA-PF) programme. The EAC wishes to explicitly state that we consider several CIDMA groups are amply capable to attract and host high-quality, postdoctoral researcher in this way. As a general rule, the various annual calls for European and other funding should be noted well in advance (e.g. the current MSCA-PF call just opened and closes in September 2023) so that it is possible to plan correspondingly. The breadth of expertise of the centre should provide numerous opportunities for such collaborations.

## 5.1 Teaching and Related Service

The EAC noted that CIDMA members generally carry a significant workload in teaching and related activities. Since an increase of staff members for teaching at CIDMA in order to reduce the teaching workload of the individuals seems difficult, other possibilities could be considered. One option is student tutors supporting the teachers with exercise sessions, correcting exams, and in the organization of bigger classes. A reduction of hours spent in the teaching process could be invested in hours to do research.

## 5.2 Financial Reports

The financial reports show that the funding is allocated to cover reasonable expenses associated with typical needs, such as visits between members of CIDMA, costs for visits and participation in international conferences to present results and achievements, basic computing equipment, computing time on high-performance computers.

The EAC notes that internally, CIDMA management allocates a certain proportion of the centre's funding to each group with the freedom to allocate it to eligible expenses as the group thinks best. This is important because different groups have different needs to carry out their research activities.

The financial information we received only reported on the use of FCT base and programmatic funding. This could be extended by figures on how much project-related funding was generated each year, as well as revenue from projects with industry and other non-research funding sources. This would further highlight the strengths of CIDMA and the potential for growth in funding from these sources.

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<sup>4</sup><https://www.natcor.ac.uk>

<sup>5</sup><https://www.lnmb.nl/>

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### 5.3 Annual Reports

The EAC was provided with the Annual Reports of both the base and programmatic aspects of CIDMA for the past three years. We have no additional comments on these; our reflections on the research activities and management of CIDMA are contained elsewhere in this report.

### 5.4 Industrial Activities

CIDMA has very close collaborations with the industry, and students on master and PhD level are involved in industrial projects. This is exceptional, and very valuable not only for the industrial partner but also for the students, who get in contact with real world problems already at an early stage. One could make use of these contacts to organize meetings with faculty members (particularly PhD and Postdoc students) and industrial partners for an exchange of experiences. Former students working in the industry could provide feedback and give recommendations.

### 5.5 Further Recommendations

Overall the EAC were impressed with the high quality of the broad research activities and outputs in CIDMA, and our detailed assessments can be found in the above sections. Our reports on the individual research groups and thematic lines above contain various detailed recommendations and suggestions. We do not repeat those here but refer the reader to the above sections.

In the light of our discussions with researchers and students, we also make the following general suggestions for improvement within CIDMA:

- It would be helpful to have a more formal induction process or welcome day for new members, largely covering administrative matters.
- More frequent opportunities for informal interactions, for example over coffee, would be welcomed.
- We encourage the continuation of a regular (though not necessarily frequent) colloquium aimed at a broad mathematical audience. The purpose of such a colloquium is to increase awareness and understanding within CIDMA of what every group is doing, and thus encourage more research collaborations and projects across groups.
- An increase of the conference budget for some PhD students would be important for increasing their experience in presenting in front of an international audience, and for establishing contacts with internationally renowned scientists.
- Several PhD students and PostDocs expressed interest in learning about career opportunities outside academia. CIDMA should consider organizing annual career panels for Masters and PhD students and Postdocs, with a panel consisting of industry representatives and UA alumni.

- The two industry-focused TLs, MI and TFC, would benefit by being maintained as separate foci for interacting with industry, with the former focusing on the networking aspects and on matching industry needs with the relevant mathematical expertise within CIDMA, and the latter focusing on the transfer of said expertise to industry and the practical implementation of solutions to industry problems.

## 5.6 Final Considerations

The EAC committee confirmed a special effort in fostering and enhancing collaboration across the various research groups in terms of co-publication, and joint projects and activities. It should be acknowledged, though, that this requires time and energy given the very high number of researchers involved in this unit. In particular, the leaders of the thematic lines are pushing to have more involvement both from groups as a whole and individual researchers.

Publication in top-journals is of course important and should also be encouraged while it also matters to have a strong outcome of publications and citations among the groups and within each group. Given the inclusive philosophy of CIDMA, these issues mean a true challenge for the administration of the centre, and for the group and the thematic line leaders. The EAC strongly encourages exploring ways to achieve improvements in these important points that would make it more likely to increase CIDMA's evaluation in future funding applications.

### External Advisory Committee

Aveiro, 10 May 2023



Miguel Anjos  
Univ. of Edinburgh



Hans G. Feichtinger  
Univ. of Vienna



Peter Filzmoser  
TU Wien



Massimo Lanza de Cristoforis  
Univ. of Padova



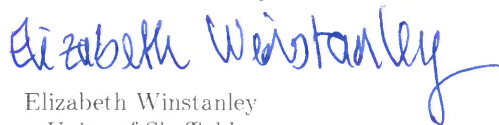
Snezana Lawrence  
Middlesex University



Pablo Pedregal  
Univ. de Castilla-La Mancha



Egon Schulte  
Northeastern University



Elizabeth Winstanley  
Univ. of Sheffield