Universitat Politècnica de Catalunya ▪ BarcelonaTech

IMTech 2

Newsletter

December 2021

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IMTech Newsletter

Issue 2, December 2021

The first year

Contents

Editorial

Even though the closing of this issue was delayed by the pressures on everybody caused by the Covid-19 pandemic, we have maintained December 2021 as the publication month in order that the first two issues are counted as belonging, as initially intended, in the year 2021. Let us hope that more favourable circumstances will allow us to stick to our plan of publishing the two issues of 2022 in June and December.

The **Interviews** in this issue have been with:

- Alícia Casals (UPC)
- Joan Bruna (CIMS)
- Joaquim Serra (ETH)
- Jordi Tura (Lorentz Institute)

We gratefully appreciate their effort and time to answer our questions, which will surely interest our readers.

We are glad to have ten **PhD highlights** in this issue. The list of their names, ordered column-wise by the reception date of their summaries, is as follows:

- Robert Cardona
- Cédric Oms
- Guillem Blanco
- Juan C. Felipe
- Jordi Roca
- Jordi Vila
- Vasiliki Velona
- Marina Garrote
- David Codony
- Xavier Rivas

Congratulations to all for their successful research, not only the new PhDs for what amounts to a landmark step in their careers, but also the institutional units and people, including their doctoral advisors, that provide the needed catalyzing structures and arrangements.

In the **Outreach** section you can find two pieces. One, authored by Simeon Ball , is about Quantum Error-Correction, and the other, authored by Ricard Gavaldà , is about Data analytics for efficient healthcare. There are further pointers to these authors in the **Reviews** section. Concerning Ball, you can find a review of his book *A Course in Error-Correcting Codes* and of two of his recent papers . In the case of Gavaldà, there is a review of the book *Machine learning for data streams, with practical examples in MOA*, co-authored with A. Bifet, G. Holmes and B. Pfahringer.

This time we include three **Chronicles**. The first, by Guillem Perarnau and Juanjo Rué, is about the **The European Conference on Combinatorics, Graph Theory and Applications** (Eurocomb-21 , 6-10 September 2021), which was a success despite the fact that it had to be held fully online. The second, by Amadeu Delshams, is about the production of the Collection ICIAM 2019 SEMA SIMAI Springer Series with one volume for the plenary lectures and thirteen volumes stemming from minisymposia organized within ICIAM 2019. And the third chronicle, by Maria Alberich and Sebastià Xambó, is about the exhibit deployed from September 22 to December 17 at the FME, with support from **IMTech**, titled Imaginary: A mathematical symphony ("Una simfonia matemàtica" in Catalan).

There is an enthralling **Event** ahead, as depicted by Gemma Huguet and Marcel Guardia: The Tere Martínez-Seara's Fest on the occasion of the conference *Global and local aspects in dynamical systems: From Exponentially small phenomena to Instability* (GLADS-22, 5-9 July, 2022). The list of topics includes:

- Global dynamics in Hamiltonian systems
- Exponentially small phenomena
- KAM theory
- Arnol'd diffusion
- Invariant manifold theory
- Celestial Mechanics
- Systems with impacts
- Action-minimizing orbits and measures

In **Reviews** we include five books including the two mentioned before, and six papers , including Joaquim Serra's overview of his work in the *EMS Magazine* (June 2021) on the occasion of having been awarded the EMS Prize for young researchers.

One of the **Chronicles** featured in the NL01 was the Abel Prize 2021, awarded to Lásló Lovász and Avi Wigderson. Now the last *EMS Magazine* (December 2021) has published an extensive interview with them, conducted by Bjørn I. Dundas and Christian F. Skau, in which they answer questions about their main contributions, their wide significance, and also about the very deep links between Discrete Mathematics and Computer Science.

We wish for all of you, contributors and readers, a most happy and productive 2022.

Alícia Casals is Professor in the Automatic Control Department of the Technical University of Catalonia (UPC). She leads the Research Group on Intelligent Robotics and Systems of the Biomedical Engineering Research Centre (CREB-UPC).

Her background is in Electrical and Electronic Engineering (ETSEIB), with a PhD in Computer Vision (FIB). Her research field is in robotic systems and control strategies for rehabilitation, assistance and surgical applications. Among other projects, she is leading the UPC node of the European projects SARAS (Smart Autonomous Robot Assistant Surgeon) and ATLAS (Autonompus Intraluminal Surgery). The research in this field has led to the creation of the companies RobSurgical Systems and Surgitrainer. She is member of the Biomedical Engineering and the Automation, Robot and Vision PhD Programs at UPC.

In 1996 she received the City of Barcelona Prize and in 1998 the Narcís Monturiol Medal of the Catalan Government in recognition of Scientific and Engineering Merit. She has had various responsibility positions in the Robotics and Automation, and in the Medicine and Biology societies of IEEE.

Since 2018, she is President of the Science and Technology Department (Secció de Ciències i Tecnologia) of the Institute of Catalan Studies (IEC).

NL. ***Your PhD research was on Computer Vision. Were you already motivated to work on robotics or the switch to this realm came later?***

AC. Computer Vision (CV) was first, robotics was still an unknown discipline in our country by that time. Research was not so common when I started my academic career, back in 1978, by joining the Facultat d'Informàtica (FIB), which was created just at the time of my graduation. Then the big question was –what kind of research could we do? The first steps were towards investigating the possibility of using ternary logic, instead of binary logic, to achieve more computing power. But comparing the higher complexity of building a *trit* with its information gain with respect to a *bit* showed that the idea was not really worth being pursued. Then, we decided to move to CV, quite new and challenging by then. And from the first applications of CV for industrial applications, the research moved to robotics. Although the first robots began to be installed in the car manufacturing sector, it was a quite limited area of application and it was a big challenge for us to discover the technology behind and start doing research and teaching these matters. We were the first in introducing robotics at the academic level in Spain, also in giving courses for industry and international seminars as well. We started investigating on the basics of robots and later going deeper on robot control and intelligence, usually relying on the information provided by images. And until now we have kept working on vision and other perception means, first for industry, later for service robots, and now mainly for medical robot applications and medical diagnosis.

How would you describe the main themes of the engineering projects and problems you have been interested in?

The main topic of research and development has been providing certain level of intelligence to automatic and robotic systems. This research has led to the development of projects in many different application fields. As mentioned, first vision-based systems for industrial applications, then automation and robotics for industry and services, later underwater robotics, and in more recent times, assistance and rehabilitation robotics in the field of surgical robotics. Medical robotics is now the main focus of our research. All our robot projects have a common basis: sensing and perception systems that provide information for the robot's control. But it is to be stressed that each application field demands specific requirements and that the wide variety of working conditions and constraints always pose new challenges.

Besides engineering, what other professional endeavors have been driving your career?

When I was a child, teaching was the profession I dreamed to become, although by then I imagined working in schools for primary and secondary studies, the context I knew. My academic career has been basically focused on teaching and doing research at the university, but also on entrepreneurship, participating in the creation of several spin-off companies. In any case I think that our duty is wider than the strict roles of teaching and doing research and innovation.

I have been quite open to contribute to spread science and technology at different levels and audiences, from the elder to children, and from technicians to the general public. Research may be limited to study, investigate, and develop in isolation, but globally research grows also thanks to the organization of events and management of societies and institutions that coordinate activities and spread knowledge. Therefore, I think it is the duty of a researcher to be involved in such activities and if possible taking responsibilities. I have been an active part in the launching of the European Robotics Network (EURON), and in being member of its board, initiatives that really gave a push to the creation of a European robotics community. I have also participated actively in the Institute of Electrical and Electronical Engineering (IEEE) through the Robotics and Automation Society and the Engineering in Medicine and Biology Society (EMBS), in which I'm still active. I have been editor, associate editor or reviewer of many national and international journals. I have taken responsibilities or commitments in academic committees, in evaluation processes or assessing and consulting committees at the University level; in Barcelona, in Catalan, Spanish and European institutions (plus other sporadic international actions). At present I am President of the Science and Technology Section of the IEC and also trustee of the Universitat de Vic.

As a woman in science, another commitment is mentoring or promoting the interest among young girls for technology and in general for STEM matters, as well as becoming a referent to give visibility to women in responsibility positions and move forwards toward equity. Thus, interventions as a "reference woman" in matters where women are scarce is another role in my career. That is, taking part in debates, lectures, consulting, mentoring, etc. And finally, due to the ethics issues related to robotics and artificial intelligence, I participate in talks and debates in topics related to how technology affects the society an analyze how to face its progress.

Can you share your views about the role of mathematics in engineering in general?

Working in robotics it's obvious the high level of mathematics required to solve problems: the geometry required to calibrate a camera and a robotic system, the mathematical solutions to robot kinematics and dynamics, the calculations required to solve the physics of interacting with objects, the modeling of deformable objects, computing the value of physical variables from measured data from sensors, and so on.

But we may also find infinitely many examples in industry. Visiting a factory long ago, I was surprised with the process of printing a name, a number, a drawing or a mark on a non-flat lid of a metal tin or a bottle tap, while keeping the expected appearance without deformations. I had never thought on the process before, that is, on how mathematical and technical issues can appear for instance in the manufacturing of a simple object that we use frequently in our daily life. This is just an example. More involved examples are the models from 3D printing or figuring the expedition times in a warehouse, among many others.

At another level, we may consider the mathematics applied in space engineering, like computing distances from measures taken at different points, or a trajectory from a moving planet to another target that has different dynamics and is under the effect of other external forces.

Or let's notice how the coronavirus pandemic has shown the value of statistics and mathematical modelling to foresee its evolution and help in taking decisions.

When it comes to enroll new members with a mathematical education to one of your engineering teams, what profiles do you value best?

We need expertise in different disciplines depending on the project or part of a project, either computer engineering, industrial engineering, control and automation, electronic design and microprograming, mechanics, and in all cases with a minimum of mathematical level, and some of them with a solid base on mathematics and physics. However, I have to say that in many projects what really counts is the candidate's general attitude, vocation, common sense and interest, just because our research involves multidisciplinary knowledge, initiative and real interest on the science behind every problem and solution. Of course, profiles combining two or more degrees or masters are ideal, particularly a combination of mathematics or physics with a more technical/engineering background, as it usually presages an open mind and a strong problem solving capacity.

What are the biggest current mathematical challenges for robotics in general, and for remote-surgery in particular?

The more classical mathematical problem in robotics is establishing the robot kinematic model and obtain its inverse transform for its control. But much more challenges are still open to improve robot performance. One is image registration for its application to the fusion of images: to relate the position of the patient to that of the robot and to those of the pre-operation images (in general, camera and robotic systems' calibrations); or generating a full map of a scene from a series of partial images, like aerial images of a field gained from a sequence of images taken from a drone; or getting a full image of a placenta produced from the surgical exploration with a fetoscope that has a very narrow field of view.

A second challenge is the modelling of deformable tissues and objects in view of applications to either predicting the effects of its interaction with surgical tools or inferring from images the measure of an applied force (this is the concept of sensor substitution or sensorless systems), or developing simulators for training in surgery or for planning an intervention that includes visual, geometric and mechanical properties of the tissues.

Prediction is another issue, necessary to compensate delays due to measuring techniques, computing processes and communication between modules, for example in a teleoperated system.

Finally it is worth mentioning the need to design mathematical strategies to reduce calculation times of processes that require multiple iterations, or a huge number of random trials. This is the case of neural networks and deep learning in the process of training robotic systems to operate with certain autonomy. And not to forget that some kind of parallel robots, continuum robots, and in general redundant robots amount to ill posed problems that need tricky mathematical solutions.

You chaired for four years the Georges Giralt PhD Awards committee. What is your current assessment of the role played by awards in the promotion of research and knowledge transfer?

A recognition of one's work is motivating and may encourage future innovative research and development. Prizes like the Georges Giralt award is also a way to distinguish the best researchers, a way to help to promote the recipients for new positions in competitive processes since such recognitions are a positive point in a curriculum vitae. What becomes frequent news in the media is in general discouraging (political issues, crimes, disasters), so giving visibility to a good work or career helps to get a more positive view of the world. Unfortunately, an almost nonexistent benefit of awards in science and technology is its visibility to society. Artists, football players or journalists appear much more in any kind of media. Giving more importance to science and knowledge in general would make science and technology, and STEM too, more visible to the society and politicians, would help to take better decisions and motivate potential students to these fields.

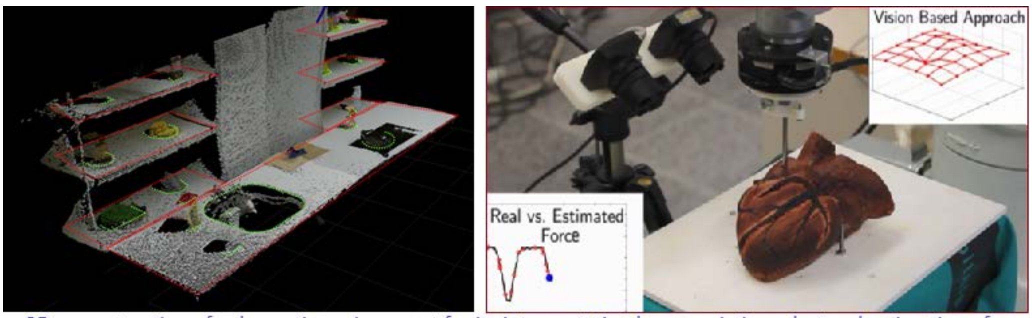
In 2005 you were the General Chair of ICRA, which is the most relevant world congress on robotics. What significance do you ascribe to that event, and to your role in it? What advice would you like to bestow to young researches concerning their attendance of conferences in general, and to world-class conferences in particlar?

The ICRA is the flagship conference of the IEEE Robotics and Automation Society. A meeting point for the robotics community worldwide and as such it was an honor being able to chair one of its editions. Holding ICRA 2005 in Barcelona gave us the chance of visualizing our university (UPC), Barcelona and Catalonia to roboticists worldwide. The hard work in the previous period was enormous for me, as well as for the UPC team that did all kind of tasks to make it run smoothly and successfully. The main message I got is that the harder the work required to make something successful, the bigger is the satisfaction of the consequent positive outcome. And let me add how one such event that requires a strong collaboration of all the team creates new ties in the group, and apart from that, it of course reinforces international relationships.

In what refers to the interest to attend conferences, I have to say that such events constitute a meeting point for people with common interests and a means to establish contacts and foresee future collaborations. Although sometimes reading an article allows going deeper than listening a short presentation, the interaction with authors is worthwhile. We should also distinguish between big conferences offering a view of the field with participation of a big community and those more focused on specific topics that allow deeper insight in one's research. Anyhow, seeing the amount of conferences offered around, one should be selective and choose the more convenient to attend. Some of them seem rather conceived for the commercial interest of the organizers and at to entice the traveling interests of attendees.

With what advanced foreign institutions do your teams sustain live collaborations?

Our main collaborations are with: Altair group (University of Verona), Scuola Superiore Sant'Anna (Pisa), Medical Robotics group at KU Leuven, LAAS-CNRS (Toulouse), Polimi (Milano), MIT AI Lab (US), Fondazione Santa Lucia (Rome), Topro industry (Norway), IEEE RAS and EMBC societies, plus specific collaborations with many other groups working in European projects. The collaborations are mostly related to research, research management or evaluation and tech transfer.



3D reconstruction of a domestic environment for its interpretation by an assistive robot and estimation of interaction forces between instrument and tissue from the visual analysis of tissue deformation.

JOAN BRUNA I ESTRACH is Associate Professor at the Courant Institute of Mathematical Sciences (CIMS) of New York University (NYU). He belongs to the Department of Computer Science, the Department of Mathematics and the Center for Data Science. He is a leading member of the group on Computational Intelligence, Learning, Vision, and Robotics (the CILVR, founded by Yann LeCun); and also belongs to the Math and Data group. JOAN BRUNA has degrees in Mathematics and Telecommunications Engineering from UPC/ CFIS, a MSc in Applied Mathematics from the ENS of Cachan, and a PhD (2013) from École Polytechnique (France), supervised by Stephane Mallat. He has been Assistant Professor of Statistics at UC Berkeley and part of the Berkeley AI Research Initiative (BAIR). At present he is the advisor of 11 PhD students and supervisor of 2 postdocs. He has engineering experience in the private sector and is the author or coauthor of 7 patents. In 2018, he was awarded a Alfred P. Sloan Research Fellowship. In 2019, he received the NSF CAREER Award for the project *Theory and Applications of Geometric Deep Learning*. In the period Fall 2019-Spring 2020, he was member of the School of Mathematics of the Institute for Advanced Study (IAS, Princeton, NJ), coinciding with the Year on Optimization and ML. Since 2020 he is Long-Term Visiting Scholar in the Center for Computational Mathematics of the Flatiron Institute of the Simons Foundation in New York. And in 2020, he received the Outstanding Paper Award of the International Astrostatistics Association.

NL. ***In the Reviews section of the NL01, the 5G monograph* (Geometric Deep Learning: Grids, Groups, Graphs, Geodesics, and Gauges) *was included (page 18). The subtitle,* The "Erlangen Program" of Machine Learning, *reveals its unifying ambition and future potential. It would be nice if you could condense into a crisp sentence, as F. KLEIN did for his program, the core of the 5G proposal. Anyway, will that monograph lead soon to a more detailed presentation in book form?***

JB. The book is indeed scheduled to be completed this year. In a sentence, the core idea is to present unifying mathematical and algorithmic principles that explain why and when it is possible to extract useful features out of geometric data in high-dimensions, across various data modalities.

We also included the remarkable paper* Neural Splines: Fitting 3D Surfaces with Infinitely-Wide Neural Networks. *Can it, or other works of yours, be regarded as illustrations of your unifying scheme?

This "quest for unification" is indeed one of the long-term drives of my research, and I published some works covering several aspects of this program. This one in particular focuses on 3D geometric reconstruction, but in the past I have also been interested in applications to particle physics, chemistry, and general foundations for graph-structured data.

Let us turn to your origins. To what degree your interdisciplinary education at the CFIS has been significant for your later career, not only in the academic world, but also in the private sector? Are there any specific crossroads that you might like to highlight?

The interdisciplinary education at CFIS has been instrumental in my career, and to some extent reflects the "scientific entropy" I was suffering by then, or, in other words, the inability to pick only one discipline amongst many interesting choices. My specific choice (Telecommunications Engineering and Mathematics) spans two distinct aspects of scientific inquiry: the theoretical aspect brought by fundamental mathematical tools, and the engineering aspect that relates these tools to practical problems. This dichotomy between applied versus theoretical questions has stayed with me ever since, and throughout my career I have in fact alternated between applied and theoretical 'periods', in academia and industry. In retrospect, these periods have fueled each other, and I see it as a privilege of us scientists to be able to work on both.

In the history of science and engineering there are plenty of milestone episodes where the mathematical foundations come first, for instance with the landmark works of Turing and Shannon. In other cases, the foundations are worked out after the applications, as variously illustrated in the evolution of thermodynamics. How do you envision the interplay between foundations and applications in the case of Deep Learning, or, more generally, Artificial Intelligence?

This is a great question. I think one could say that in the case of Machine Learning (ML) this interplay has undergone a 'phase transition'. In the early days of ML, the field was driven by foundations, dominated by algorithms with solid theoretical guarantees (such as Support Vector Machines or Kernel Methods). Then Deep Learning (DL) disrupted this state of affairs and turned these foundations upside down. We are now in a phase where theoretical efforts are descriptive –theoreticians are mostly trying to explain the current experiments–, but a time will come where theory will become prescriptive again, by informing better or more efficient algorithms.

Continuing with a similar topic, what are the new trends in neural networks that will be developed in this decade? As a result of it, do you foresee any stunning change in our everyday life?

This is very speculative, but I anticipate that neural networks will continue to permeate all areas of computational science, forcing the field to address some of its current shortcomings, such as (lack of) robustness and efficiency. From my biased perspective, I also see an incipient research community, so-called 'Scientific Machine Learning', at the interface of applied mathematics and machine learning, who will develop a novel generation of numerical tools to solve problems in computational science.

How do you see the studies of Mathematics and Statistics in Catalonia and how do they compare with those elsewhere, particularly in France and the USA?

My personal experience as an undergrad was fantastic, and certainly compares favorably with most undergraduate programs in the USA, including those from top universities. I also think that the Catalan university system is building a very strong graduate and post-graduate Mathematics program, with a brilliant young generation of mathematicians and statisticians. That said, each country has important cultural differences that may result in different outcomes. For example, France has a strong tradition of excellence across many areas of science, reflected in a very selective (albeit imperfect) public academic system (the "Grandes Écoles") that trains excellent researchers. The USA has partly delegated this role to private universities, but its innovative, immigrant and forward-looking mentality are ultimately an important factor that helps research.

A final question: Which actions could IMTech consider to attract and retain young talent?

I think that in the current era of data-driven science, mathematical foundations will become even more instrumental for progress. Applied Mathematics as a discipline will certainly need to adapt to these new times, by creating new sub-fields and embracing cross-disciplinary research. I am confident that **IMTech** will seize the opportunity and grow along these directions.

Joaquim Serra is Assistant Professor of Mathematics at the ETH Zürich (Switzerland). His research is on elliptic PDEs: regularity of interfaces and free boundaries, stable solutions of non-convex variational problems, geometric PDEs, and integro-differential equations. He earned his degree in Mathematics from UPC in 2009, as a student of the CFIS and with an Erasmus term (2008-2009) in the University of Florence. In 2010 he obtained a MSc degree in Applied Mathematics and in 2014 his PhD in the Applied Mathematics doctoral program, both from UPC and supervised by X. Cabré. His PhD thesis was a long memoir (329 pages) on *Elliptic and parabolic PDEs: regularity for nonlocal diffusion equations and two isoperimetric problems*. He was awarded the Josep Teixidor Prize of the SCM (2016, for his outstanding doctoral thesis); the Rubio de Francia Prize of the RSME (2018); the Antonio Valle Prize of the SEMA (2019); and the EMS Prize of the EMS (2020). He got a start-up grant, associated to the Rubio de Francia Prize, from the FBBVA, a SNSF Ambizione Starting Grant for the project A geometric approach to nonlinear elliptic and parabolic equations (2020 Call) and an ERC Starting Grant for the project Stable InterFaces: phase transitions, minimal surfaces, and free boundaries (years 2021 to 2025).

Photo ETH Zurich / Alessandro Della Bella

NL. ***You are a CFIS alumnus and hence you were exposed to an interdisciplinary education, which in your case had a major mathematics component. How has this training facilitated your professional career?***

JS. Math may seem sometimes difficult, but the real world is often much more complicated. Still, it is amazing that we can understand so much about the real world using math. One of the lectures I liked the most at UPC was Prof. Aguló's lab on rigid-body mechanics. There we could play with gyroscopes and other interesting devices: the equations in the blackboards came into life. It was really exciting and I wish I had had the opportunity to attain more labs like that one. In my opinion, being exposed to some "real-world" problems can only do good to us mathematicians. I think it helps us remember that math should always be a way to simplify and better understand things, and never to make them more difficult.

What was the impact on your view of mathematical research your Erasmus stay in the University of Florence?

It was a very nice experience, also for math. The math department in Florence had very strong analysts when I was there, such as Talenti (he retired in 2010) or Maggi (he is now professor at U. of Texas at Austin). I was very lucky to attend the beautiful, and quite advanced, course "Calcolo delle Variazioni" that Maggi taught. He recently told me that he taught that course just twice: the first year Guido De Philippis was a student and he just got the maximal grade "30/30 e lode". The second year I got also the same grade. So, he jokes, having top grade in his course amounted to an EMS Prize.

A major step in the life of a researcher is his PhD, which in your case was under the advice of Professor Xavier Cabré and in close collaboration with Xavier Ros-Oton. Could you reminisce about the main aspects of that singular experience?

I was extremely lucky. The advisor determines at least 50% of the success of your PhD, and Cabré was an ideal advisor in all possible metrics. Also, doing the thesis at the same time as Xavi Ros was a catalyst for our careers. We learnt that collaborations allow us to tackle more difficult problems much more effectively. It is one of the best parts of the research business: collaborations are not only fun, but they boost scientific productivity.

Your main research accomplishments so far, outstanding on all counts, are described in detail in the Review of your paper* The geometric structure of interfaces and free boundaries *included in this NL (page 24). Could describe the atmosphere that has been driving these researches and their main characters?

Cabré taught us —I think, he took that from Nirenberg— that one should think of difficult and interesting questions, but with a very humble attitude. If I do not know how to do any thinking with my PDE in 3d, no problem, can I at least do some computation in 1d? In the last years, what I tried to do is to work in simple-enough problems in which I estimated I could obtain some progress, but that were related in some way to some more classical questions which I had no idea how to tackle. For instance, during my thesis I worked a lot on integro-differential equations, where there were several approachable though natural questions. Later it turned out that many of the things I learned working on these problems were very useful in order to attack some more classical questions.

In the areas of your interest, what problems would you like to see solved during this decade?

There are very simple questions in PDE which one would say had been "overcome" during the 20th century, but which in fact are completely open. This happens for instance with very simple classical PDE from physics, such as the Allen-Cahn equation, in which interfaces or free boundaries appear. Often the solutions of the PDE are those of the Euler-Lagrange equation for critical points of some energy. And often much is known about absolute minimizers of the energy, for instance the smoothness of interfaces in three spatial dimensions, but when one considers local minimizers of these energies instead of absolute minimizers then the knowledge available becomes embarrassingly little. The fact that the theory works only for absolute minimizers is a real limitation, because physical solutions are often merely local minimizers. In particular, some problems I hope to see solved in the next few years concern the smoothness of interfaces for of stable critical points of the Allen-Cahn equation (or also the Bernoulli free boundary problem) in three dimensions.

How is your working day at ETH? What are the main tasks you have to care about? Which ones do you like best?

Some of the most time-consuming activities, besides research, is teaching. I am currently teaching the Differential Geometry course for mathematicians and physicists at ETH. It is a large course, 4h of theory + 1h exercises every week through a whole academic year. So, there is time to cover a lot. At ETH the professor teaches the theory in a large group and then the assistants teach the exercises in smaller groups. Besides this, there are department meetings, but only about once per month. We are extremely lucky that bureaucracy is really low for professors. The *sekretariat* is extremely effective and everything works smoothly. Also —and this is fundamental—, bureaucracy usually makes sense and has a reasonable purpose! So, most of my tasks are research-related: supervising bachelor and master theses, visiting students, PhD students, and postdocs. This is what I like best.

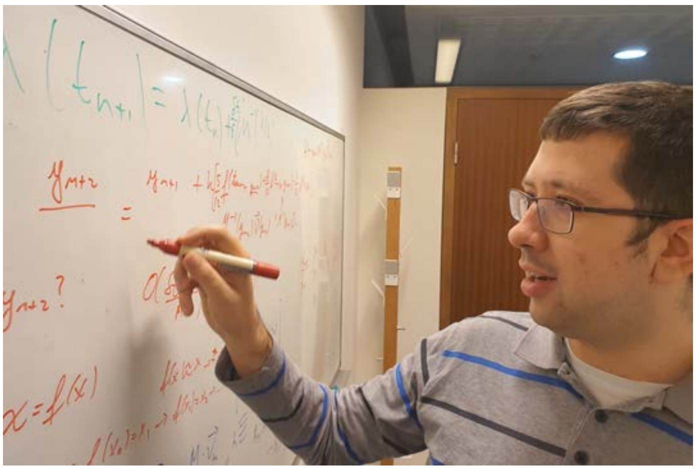
Do you think that is easier or more difficult in Spain for a young researcher to pursue an academic career? Why?

This depends... If one decides to pursue an academic career no matter what, because it is their passion, then in Spain they will have better chances to succeed. In Switzerland there is a very narrow funnel towards academic careers: to start with, a smaller fraction of the population goes to university. Also, among people who do a PhD, just a few stay in academics at the postdoc stage. At the end of the funnel, becoming a full professor at a Swiss university is very hard. However, my impression is that people are happier with their careers in Switzerland: even those who didn't go to the university often tell you they enjoy the well-paid and good-quality professional training. Similarly, most PhD's who do not pursue academic careers have typically very good jobs and their choice is not seen as a failure at all! Also, having much less professors in university departments —for instance, ETH has roughly the same number of students as UPC, but 500 professors in total— perhaps makes organization and decision-making easier. Of course every system has its advantages and disadvantages. Last but not least, for what I see Switzerland had much more power to attract leading researchers, young or not so young, and makes their life really easy so that they can focus on their research. This is not the case in Spain, for what I know.

As a last question, which actions could IMTech consider to attract and retain young talent?

Competing in science with countries like Switzerland is not a real priority of Spain, and not much can be done about it. Admitting this, Barcelona is a very nice city to live in, and there will always be scientists who prefer to live in Barcelona for personal reasons, even having to cope with all the disadvantages of Spain. What **IMTech** can certainly do is to try to convince talented mathematicians to choose it instead of other places of Spain... by creatively offering ideas to compensate some of the disadvantages of Spain. **IMTech** could also try to take advantage of some exceptional existing talent attraction tools such as ICREA.

Jordi Tura i Brugués is Assistant Professor at the Lorentz Institute for Theoretical Physics at Leiden University. He is a leader of the Applied Quantum Algorithms group, an interdepartmental initiative that comprises researchers from the Physics, Advanced Computer Science, Mathematics, and Chemistry institutes. Jordi Tura obtained a double degree in Mathematics and Telecommunications Engineering from CFIS, UPC, as well as an MSc in Applied Mathematics from UPC. He obtained his PhD at ICFO—The Institute of Photonic Sciences in 2015, under the supervision of ICREA Prof. Dr. Maciej Lewenstein. As a postdoc in the group of Prof. Dr. Ignacio Cirac, at the Max Planck Institute of Quantum Optics, he obtained a CELLEX-ICFO-MPQ, a Marie Skłodowska-Curie and an Alexander von Humboldt fellowships. At present he is the advisor of 4 PhD students and 2 postdocs. His PhD thesis has received several awards, such as the Springer Theses award or the UPC Special Doctoral Award. Since 2021 he is an editor in the journal Quantum. In 2021 he received a Google Research Scholar Award and an ERC Starting Grant. His research comprises quantum foundations, theory of entanglement and Bell nonlocality, device-independent quantum information processing, quantum algorithms and certification of near-term quantum devices. In his free time, he plays violin, having regularly participated in e.g. the Orquestra de Cambra de Vic and the Bruckner Akademie Orchester.



NL. ***Your research trajectory so far has a very marked interdisciplinary character. Could you describe the main disciplines concurring in your work and appraise the significance for your success of the CFIS education in Mathematics, Applied Mathematics and Telecommunication Engineering?***

JT. I think my CFIS education was key in giving me the background knowledge, but more importantly, also the right tools and mindset to work in a field such as quantum information. When I started, it simply clicked as the perfect combination between mathematics and telecommunications: a discipline that aligns many areas of mathematics towards the goal of processing information in a completely different way. Quantum information is a highly interdisciplinary area, becoming even more so every passing day. My CFIS education showed me how looking at problems from a different prism tends to lead to useful insights and unexpected results. I spend the day working mostly among physicists by training, so we complement each other rather well. Quantum information requires a solid mathematical base, as we employ all kinds of mathematical disciplines: numerical methods, convex optimization, functional analysis, stochastic PDEs, statistics, signal processing, multilinear algebra... yet we also need to put our engineer hats on: when we want to make existing quantum devices actually work, these are noisy and imperfect, and one needs to squeeze the most out of them, which is a non-negligible and challenging engineering task.

What was the impact in your career of the 2010 Summer fellowship at ICFO? What people there influenced your scientific development at that stage?

Without any doubt, the 2010 Summer fellowship was an inflection point in my career. The event that sparked my curiosity about quantum information was a Seminar on Quantum Processing, organized by Sebastià Xambó earlier that year, where I met my future PhD advisor, Maciek Lewenstein, and Toni Acín, the leader of the Quantum Information Theory group at ICFO. There I also met my future PhD co-supervisor, Remigiusz Augusiak. These four people certainly shaped my scientific development at that time. With Sebastià and Toni I wrote my MSc thesis, and Maciek and Remik supervised my internship and offered me a PhD position in the Quantum Optics Theory group afterwards.

You spent about four academic terms at ICFO working for your PhD under the supervision of* Maciej Lewenstein *and* Remigiusz Augusiak*. How do you recall that period?

It is one of my most cherished chapters in my life. It was fun and inspiring at the same time. I recall that Lluís Torner, the director of ICFO, during the welcoming day, told us "you should take the most out of ICFO" and, indeed, ICFO is an environment where the opportunities for learning and growing as a scientist are virtually endless. I worked with Remik on a daily basis and with Maciek whenever we were stuck or needed a fresh approach –which, amazingly, he always had. Naturally, I also worked very closely with Toni, and started to build a small network of collaborators. ICFO has created a really thriving environment, allowing one to focus solely on the research, almost in a utopical way, effectively shielding researchers from bureaucratic and other distractions. I'd say many ICFOnians quickly begin to appreciate that after leaving.

Your postdoctoal years, followed by the Marie Curie and Alexander von Humboldt fellowships at the Max Planck Institute of Quantum Optics (MPI), appear to be very rich experiences, and we would much like to know your reminiscences of them.

To me, going to the MPI of Quantum Optics was like a dream come true. Ignacio Cirac offered me a postdoctoral position in his group, I supervised brilliant students and again I could work in a great research ecosystem. I could also take many opportunities to collaborate in European consortia, and to start taking responsibility on several projects. As a postdoc I was given a lot of freedom: to pursue my research independently, to collaborate with him and/or other group members, etc. whatever worked best. In the discussions with him, one realizes how much insight and technical ability he has on almost every topic related to quantum information, and a vision for tackling the most relevant problems at the right time. I think I learnt quite a bit from him during these years, also realizing how much more there is out there. One of the best pieces of career advice he gave me was to start a new topic of research for my postdoctoral years, even though that is not the comfortable option. Naturally, while also continuing the research lines I had started during my PhD, but his advice proved very fruitful: I started researching quantum algorithms for near-term devices, which turned out to be the main area I am working on now.

Since 2020, you are Assistant professor at the Leiden University, which has a great record of discoveries in Physics, and there you lead the Applied Quantum Algorithms group. What are your main research lines for the next five years? Does your work also include experimentation? How is your typical working day?

My research for the following years focuses on the certification of quantum devices. Namely, how can we make sure that a quantum computer, big enough so that it cannot be simulated by any classical means (e.g. a supercomputer), is working as intended? One of the possible applications of this research is in cryptography, in trying to certify randomness. In other words, how could one certify, communicating with their cell phone with a quantum computer in the cloud, that a sequence of random numbers has not been produced in advance and, therefore, potentially known to an adversary. An additional challenge is that existing quantum devices are still very noisy and we cannot yet run fault-tolerant quantum error correction to suppress the logical error rate to arbitrarily low levels. This is a key restriction in making these schemes implementable on a real device, and the quantum algorithms that one must run are very far from textbook algorithms, most still yet to be developed. In Leiden we are in close contact with experimentalists in designing and bench-marking these new algorithms. My typical working day is quite different every day, and that's what I love about my work. Common things about my working day include getting up to speed with recent literature, discussions with my students and collaborators, a bit of teaching, lots of zoom meetings (too many), but I allocate some time every day purely to research.

Could you summarise what are your main scientific contributions so far?

In device-independent quantum information processing, I started the field of detection of Bell correlations in many-body systems in an experimentally-friendly way. Bell correlations are a kind of statistics produced in quantum systems that show that they do not come from any "intuitive" theory (a so-called local hidden variable model). These are a resource for device-independent quantum information processing tasks, such as quantum key distribution or self-testing. My theoretical work was soon after implemented in Bose-Einstein condensates and thermal ensembles by different experimental groups, which merited e.g. the Ehrenfest Prize 2017 for quantum foundations. We connected these notions to measuring the ground state energy of many-body spin systems in order to detect Bell nonlocality also in large one-dimensional systems, and I proposed a hierarchy of semi-definite programs to approximate from outside the set of classical correlations of a many-body system, allowing to easily derive Bell inequalities solely from experimental data.

In ground state preparation, which is a central task in quantum information, we proposed a new quantum algorithm that was faster and using less ancillary qubits than those at the time. We also proposed an algorithm for adiabatic spectroscopy, a variational approach of the adiabatic algorithm for ground state preparation that is amenable to near-term devices, which we are currently exploring with Lukin's group at Harvard.

In the domain of quantum state verification, we proposed a protocol to prepare and certify a broad family of physically relevant quantum states that are called tensor network states. I also have several works on the theory of entanglement in symmetric states and the self-testing of quantum devices.

What relations would you highlight between Quantum Information and realms such as Quantum Computing, Cryptography, or Machine Learning, at present and in the near future?

I find it amazing how Quantum Information has impacted other disciplines as well. Indeed, Quantum Computing is perhaps the first that comes to mind; still, paradigm-shifting algorithms are discovered every day, for instance the Quantum Singular Value transformation by Gilyén et al., only in 2019.

In cryptography, I'd say Quantum Information boosted the interest in post-quantum cryptography methods, such as lattice cryptography, learning with errors problems, etc. but also for certification protocols for quantum devices, whose security proof relies on problems that are thought to be hard, even for a quantum computer.

In the domain of machine learning (ML), there has been an exponential increase of papers in the last 5 years, which I could witness first-hand, working with pioneers of the field like Peter Wittek (1980-2019) at ICFO or Vedran Dunjko at Leiden. I'd say the field of Quantum Machine Learning is so vast (encompassing all sorts of Quantum-enhanced ML for Classical problems, Classical ML for Quantum applications) that there is much to be done in the next few years, especially in the rather unexplored quantum-input, quantum-output machine learning.

A final question is about you as a professional musician. We would like to hear from you how your musical career has unfolded up till now and what are your plans at this point of your life?

Music and, in particular, playing violin, has always accompanied me since an early age. In the years I lived in Catalunya, I was very fortunate to learn from great musicians such as the conductor Jordi Mora or the violinist Joel Bardolet, with whom I have a treasured friendship. I used to play in the Orquestra de Cambra de Vic during the weekends and in the Orquestra Simfònica Segle XXI during summer breaks, and it was always a very rewarding experience, a challenge seemingly quite orthogonal to science, in a rather unique environment: I could play along amateurs, students and professional musicians, all sorts of symphonic repertoire. And it was a most convenient coincidence that my following career step led me to Munich, where I could join the Bruckner Akademie Orchester, also conducted by Jordi Mora. Every now and then, we still meet with musicians from the orchestra to play chamber music, though Covid has forced us to go to standby mode. Now, in the Netherlands, I am also looking for nice opportunities to keep learning and enjoying music.

Robert Cardona Aguilar defended his PhD thesis "The geometry and topology of steady Euler flows, integrability and singular geometric structures" (pdf), supervised by Professor Eva Miranda, on 26 May 2021 within the UPC doctoral program in Applied Mathematics. Currently, he is a postdoctoral research fellow at UPC and will move to the Université de Strasbourg with a postdoctoral grant of the Laboratoire d'excellence Institut de recherche en mathématiques, interactions et applications, a project of the Centre National de la Recherche Scientifique in France.

Thesis summary: In this thesis, we make a deep investigation of the geometry and dynamics of several objects (singular or not) appearing in nature. The main goal is to study rigidity versus flexibility in the dynamical behavior of the objects considered. In particular, we inspect normal forms, h-principles, classifications, and existence theorems. These concern a series of objects which are either close or far away from what we call "integrable situations" in the sense of Frobenius' theorem and the existence of first integrals. Such dynamical systems arise in the context of the Euler equations in hydrodynamics, Reeb fields in contact geometry, and Hamiltonian systems in symplectic geometry (and their singular counterparts).

The first chapter establishes results on the universality properties of steady Euler flows, analyzing Reeb fields in contact manifolds and their close allies in the study of Euler flows (Beltrami vector fields). We extend the h-principles from the contact realm to that of Beltrami vector fields. This enables us [8] to consider universality properties, as introduced by Tao, of steady Euler flows by analyzing those of high-dimensional Reeb flows in contact geometry. In the same spirit, we address [9] the construction of steady Euler flows in dimension 3 which simulate a universal Turing machine, using tools coming from symbolic dynamics. In particular, these solutions have undecidable trajectories, unveiling that non-computable phenomena occur in hydrodynamics, answering a question raised by Moore in the 90s. In all these discussions, a key role is played by different classes of vector fields such as geodesible, Beltrami, and Eulerisable fields.

In the second chapter, we set up [1] the study of the relations between such classes in higher odd-dimensions, showing that new phenomena arise as soon as one leaves the realm of three-dimensional manifolds. For these high dimensional Euler flows (or more generally, flows admitting a strongly adapted one-form), we show [3] that they satisfy the periodic orbit conjecture, which was known to be satisfied with the stronger assumption of geodesibility. We also give [2] classification results of steady Euler flows which admit a Morse-Bott first integral using techniques coming from the symplectic world, and study obstructions arising from the ambient topology. This can be understood as an inverse problem to Arnold's structure theorem for ideal fluids, a question already suggested by Sullivan in 1995.

As other integral objects, we consider in chapters three and four integrable systems [4] appearing in symplectic manifolds and on singular symplectic manifolds. Singularities show up naturally on these phase spaces by considering manifolds with cylindrical ends and studying b-symplectic forms as initiated by Guillemin-Miranda-Pires. Other types of singularities are folded structures originally considered by Martinet and then by Cannas da Silva, Guillemin, Woodward for geometrical purposes. Our analysis includes [5] an isotopy classification of folded symplectic surfaces, the existence of action-angle coordinates on folded symplectic manifolds [6], and a correspondence [7] between the recently introduced b-contact forms and Beltrami fields on b-manifolds.

Highlighted publication: [9].

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Cédric Oms defended his PhD thesis *Global Hamiltonian Dynamics on Singular Symplectic Manifolds* (pdf), supervised by Professor Eva Miranda, on October 2, 2020, within the UPC doctoral program in Applied Mathematics. Currently, he is a post-doctoral student at the *Unité de Mathématiques Pures et Appliquées* at the *École Normale Supérieure* in Lyon.

Thesis Summary. This thesis studies the Reeb and Hamiltonian dynamics on singular symplectic and contact manifolds. Those structures are motivated by singularities coming from classical mechanics and fluid dynamics.

The branch of symplectic and contact geometry emerged as a set-up for the study of classical Hamiltonian systems, as for instance celestial mechanics. The equations of motion of the Hamiltonian system can be geometrically interpreted as the flow of the Hamiltonian vector field associated to the smooth energy function H, called Hamiltonian, on a symplectic manifold (W, ω). The holy grail in Hamiltonian systems is to establish existence of periodic orbits. Contact manifolds appear as level-sets of H and the Hamiltonian dynamics can be described intrinsically using the Reeb vector field. Whenever there are singularities in the Hamiltonian system, the approach of classical symplectic and contact topology fails. However many Hamiltonian systems coming from fluid dynamics or celestial mechanics do admit singularities and hence it is crucial to understand the dynamics whenever there are singularities in the geometric structure.

In the contact realm, the singularities considered in this thesis consist of a generalization of contact structures where the non-integrability condition fails on a hypersurface called the *critical hypersurface*. Those structures are called b-contact structures. In particular they arise from hypersurfaces in b-symplectic manifolds that have been studied extensively in the past. Formerly, this odd-dimensional counterpart to b-symplectic geometry has been neglected in the existing vast literature.

The first chapter of this thesis, the local geometry of those manifolds is examined using the language of Jacobi manifolds, which provides an adequate set-up and leads to understanding the geometric structure on the critical hypersurface.

Topological obstructions to the existence of those structures are studied and the topology of b^m-contact manifolds is related to the existence of convex contact hypersurfaces. The results concerning the topology and geometry of b-contact manifolds can be found in [2].

The next chapter delves into the dynamical properties of the Reeb vector field associated to a given b^m-contact form. The relation of those structures to celestial mechanics underlines the relevance for existence results of periodic orbits of the Hamiltonian vector field in the b^m-symplectic setting and Reeb vector fields for b^m-contact manifolds. In this light, it is proven that in dimension 3, there are always infinitely many periodic Reeb orbits on the critical surface. However, explicit examples without periodic orbits away from the critical set are given. In contrast to contact topology, it is shown that there exist traps for this vector field. We prove that the well-known Weinstein conjecture holds for compact b-contact manifolds that satisfy some additional conditions. The mentioned results shed new light towards a singular version of that conjecture.

Finally, the obtained results are applied to the particular case of the restricted planar circular three body problem, where the results from previous chapters imply that after the McGehee change, there are infinitely many non-trivial periodic orbits at the manifold at infinity for positive energy values. The results on the dynamics of the b-Reeb vector field can be found in [2]. See also the continuation [3], where a semi-local version of the singular Weinstein conjecture is proved.

Highlighted publication: [1].

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Guillem Blanco defended his PhD thesis *Bernstein-Sato polynomial of plane curves and Yano's conjectures* (pdf) on April 16th, 2020. The thesis was produced within the UPC doctoral program in Applied Mathematics and was supervised by Professors Maria Alberich-Carramiñana and Josep Àlvarez Montaner. Currently, he is an FWO postdoctoral fellow at the Algebra Section of KU Leuven.

Thesis summary. The research in this thesis focuses on the study of invariants of algebraic singularities. The main problem considered in the thesis was the study of the roots of the Bernstein-Sato polynomial in the case of plane curve singularities.

The roots of the Bernstein-Sato polynomial $b_f(s)$ associated to a singular polynomial $f \in \mathbb{C}[x_1, \ldots, x_n]$ are negative rational numbers connected with many other invariants of the singularity. The main difference between the majority of the invariants of f studied in the literature and the Bernstein-Sato polynomial $b_f(s)$ is that the later is not a topological invariant. Usually, this makes $b_f(s)$ a harder object to study.

The specific problem that was solved in the thesis regarding this invariant is the determination of all the roots of $b_f(s)$ in the case of generic plane curves in the same topological class. This problem is, precisely, the statement of a long-standing conjecture posed by T. Yano in 1982. Yano's conjecture predicts that if f is irreducible, all the roots of the Bernstein-Sato polynomial of generic curves in a topologically trivial deformation of f can be determined by the topological data of f. In addition, Yano gives an explicit set of candidates for the set of generic roots from the numerical datum of the resolution of f.

This conjecture was only known to be true in a few particular cases. The first result obtained in this direction was a proof of the general case but under some mild hypothesis on the eigenvalues of the monodromy of f. This approach consisted of studying the analytic continuation of the complex zeta function associated with the singularity [5]. The poles of this zeta function are linked to roots of the Bernstein-Sato polynomial via the Bernstein-Sato functional equation.

The approach that lead to a complete proof of the conjecture focused on the Gauss-Manin connection of an isolated singularity.

This approach consisted of constructing the asymptotic expansion of period integrals in the Milnor fiber using resolution of singularities [1]. The roots of the Bernstein-Sato polynomial can be connected with the so-called Gauss-Manin exponents using some classical results of Malgrange and Varchenko.

In the thesis other invariants of singularities were also studied [2–4, 6, 7]. For instance, the author worked on a question of Dimca and Greuel on the quotient of the Milnor and the Tjurina algebra of plane curves. In the thesis a positive answer to this question for the case of plane irreducible curves is presented [2]. More remarkably, to solve this question, a closed formula for the minimal Tjurina number in a topological class of plane branches is given, a problem that originally went back to Zariski.

Highlighted publication: [1].

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Juan Carlos Felipe Navarro defended his PhD thesis *Qualitative properties of solutions to integro-differential equations* (pdf), supervised by Professor Xavier Cabré, on 14 July 2021 within the UPC doctoral program in Applied Mathematics. Currently, he is a postdoctoral researcher at the University of Helsinki.

Thesis summary: The thesis is devoted to the analysis of elliptic PDEs and related problems. It is mainly focused on the study of qualitative and regularity properties of solutions to integro-differential equations. The study of such equations has attracted much attention recently since they arise naturally in different areas when dealing with processes where long range interaction phenomena appear. The canonical example of integro-differential operators is the fractional Laplacian, which is translation, rotation, and scale invariant.

Part I concerns the study of uniqueness and regularity properties of solutions to integro-differential linear problems. First, we prove, by following a nonlocal Liouville-type method, the uniqueness of solutions in the one-dimensional case, in the presence of a positive solution or of an odd solution vanishing only at zero [3]. As an application, we deduce the nondegeneracy of layer solutions (bounded and monotone solutions) to semilinear problems of Allen-Cahn type. Next, we establish the first boundary regularity result for the Neumann problem associated to the fractional Laplacian [1]. We prove that weak solutions are Hölder continuous up to the boundary by developing a delicate Moser iteration with logarithmic corrections on the boundary. We also establish a Neumann Liouville-type theorem in a half-space, which is used together with a blow-up argument to show higher regularity of solutions.

Part II of the thesis is focused on the study of the saddle-shaped solution to the integro-differential Allen-Cahn equation. These solutions, whose zero level set is the Simons cone, are expected to be the simplest minimizers which are not one-dimensional to the local and nonlocal Allen-Cahn equation in high enough dimensions. It plays, thus, the same role as the Simons cone in the theory of minimal surfaces. First, we study the saddle-shaped solution for the fractional problem by using the extension problem [4]. We establish its uniqueness and, in dimensions greater or equal than 14, its stability. As a byproduct, we give the first analytical proof of a stability result for the Simons cone in the nonlocal setting for such dimensions. The key ingredient to prove these results is a maximum principle for the linearized operator. Next, we study saddle-shaped solutions for any rotation invariant and uniformly elliptic integro-differential operator [5, 6]. In this scenario, we need to develop some new nonlocal techniques since the extension approach is not available. In this respect, our main contribution is a characterization of the kernels for which one can develop a theory of existence and uniqueness of saddle-shaped solutions. Under these assumptions, we establish an energy estimate for doubly radial odd minimizers and some properties of the saddle-shaped solution, namely: existence, uniqueness, asymptotic behavior, and a maximum principle for the linearized operator.

Finally, in Part III we develop a nonlocal Weirstrass extremal field theory [2]. In analogy to the local theory, we construct a calibration for the nonlocal functional in the presence of a foliation made of solutions when the nonlocal Lagrangian satisfies an ellipticity condition. The model case in our setting corresponds to the energy functional for the fractional Laplacian, for which such a calibration was still unknown. The existence of the calibration allows us to prove that any leaf of the foliation is automatically a minimizer for its own exterior datum, with no need to have an existence result of minimizers, neither to know their regularity.

Highlighted publication: [5].

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Jordi Roca Lacostena defended his PhD thesis *The embedding problem for Markov matrices*, supervised by Professors Marta Casanellas Rius and Jesús Fernández Sánchez, on 18 May 2021 within the UPC doctoral program in Applied Mathematics. Currently, he is a researcher and data scientist at Amalfi Analytics, a UPC spin-off focused on the use of artificial intelligence and machine learning for health and clinic management.

Thesis summary: The goal of this thesis is to solve the embedding problem for Markov matrices, posed by Gustav Elfving in 1937. This problem consists in deciding whether a given non-negative square matrix M with rows summing to 1 (Markov matrix or transition matrix) can be written as $M = \exp(Q)$ for some real square matrix Q with rows summing to zero and non-negative off-diagonal entries). In this case, such a Markov matrix is said to be embeddable and Q is called a Markov generator for M.

The embedding problem is motivated by Markov processes, which are used to model the change of state of a random variable over time under the assumption that future is independent from past given the present. In this framework, the entries of Markov matrices represent the substitution probabilities between states along a fixed time interval. When these probabilities are considered to be continuous (and differentiable) functions depending on time, then the process is ruled by the instantaneous rates of substitution between states, which are usually assumed to be constant with respect to the time in order to keep the process tractable. In this context, the Markov process is said to be a homogeneous Markov process in continuous-time and the substitution rates ruling it are displayed all together in a rate matrix Q. By construction, the substitution probabilities between states after time t correspond to the entries of the matrix $M(t) = \exp(Qt)$ for all $t \geq 0$. Hence, the embedding problem is equivalent to decide whether the substitution process given by a transition matrix could potentially arise from a homogeneous Markov process in continuous-time. It is worth noting that, in this case such a transition matrix may admit more than one Markov generator, each corresponding to a different underlying continuous-time process with the same terminal substitution probabilities but with different values for the intermediate substitution probabilities. The study of the uniqueness of Markov generators is known as the rate-identifiability problem and it is also studied in this thesis.

Prior to the results presented in the thesis, the embedding problem was already solved for 2×2 and 3×3 Markov matrices, as well as for some other particular cases such as Markov matrices close to the identity or Markov matrices with different real eigenvalues. However, these solutions took around fifty years to be found. The characterization of 4×4 embeddable matrices did not only mean solving the embedding problem for the smaller size of matrices for which it is not solved, but also had practical consequences in biology. Indeed, Markov processes are typically used in the context of phylogenetics to model the substitution of nucleotides over time in a given DNA sequence. The embedding problem appears related to fundamental questions concerning the consistency and definition of some of the resulting nucleotide substitution models.

In this thesis, we present a method to decide whether a Markov matrix with different eigenvalues (real or not) is embeddable. This effectively solves the embedding problem in a dense subset of Markov matrices for any size. Moreover, we also provide a explicit solution for all 4×4 Markov matrices and the resulting criteria for embeddability when restricted to some commonly used nucleotide substitution models, such as Kimura models and the strand-symmetric model. We also show that the proportion of embeddable matrices (i.e. those potentially arising from a continuous-time version of the model) decreases as the model constraints are relaxed. More precisely, we observed that the proportion of embeddable matrices lies in the range between the 0.05% and the 75% depending on the complexity of the model, showing that the restriction to time-continuous nucleotide substitution models might be much more restrictive than expected.

Highlighted publication: [1]

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Jordi Vila Pérez defended his PhD thesis *Low and high-order hybridised methods for compressible flows* (pdf), supervised by Professors Antonio Huerta and Matteo Giacomini, on February 10, 2021, within the UPC doctoral program in Applied Mathematics. Currently, he is a Postdoctoral Associate at the Aerospace Computational Design Laboratory of MIT, where he is working on a project sponsored by the National Science Foundation under the supervision of Jaume Peraire and Ngoc Cuong Nguyen.

Thesis Summary. The aerospace community is challenged as of today for being able to manage accurate overnight computational fluid dynamics (CFD) simulations of compressible flow problems. Well-established CFD solvers based on second-order finite volume (FV) methods provide accurate approximations of steady-state turbulent flows, but are incapable to produce reliable predictions of the full flight envelope. Alternatively, promising high-order discretisations, claimed to permit feasible high-fidelity simulations of unsteady turbulent flows, are still subject to strong limitations in robustness and efficiency, placing their level of maturity far away from industrial requirements. In consequence, the CFD paradigm is immersed at this point into the crossroads outlined by the inherent limitations of low-order methods and the yet immature state of high-order discretisations. Accordingly, this thesis develops a twofold strategy for the high-fidelity simulation of compressible flows introducing two methodologies, at the low and high-order levels, respectively, based on hybridised formulations.

First, a new finite volume paradigm, the face-centred finite volume (FCFV) method, is proposed for the formulation of steady-state compressible flows. The present methodology describes a hybrid mixed FV formulation that, following a hybridisation process, defines the unknowns of the problem at the face barycenters. The problem variables, i.e. the conservative quantities and the stress tensor and heat flux in the viscous case, are retrieved with optimal first-order accuracy inside each cell by means of an inexpensive postprocessing step without need of reconstruction of the gradients. Hence, the FCFV solver preserves the accuracy of the approximation even in presence of highly stretched or distorted cells, providing a solver insensitive to mesh quality. In addition, the FCFV method is a monotonicity-preserving scheme, leading to non-oscillatory approximations of sharp gradients without resorting to shock capturing or limiting techniques. Finally, the method is robust in the incompressible limit and is capable of computing accurate solutions for flows at low Mach number without the need of introducing specific pressure correction strategies.

In parallel, the high-order hybridisable discontinuous Galerkin (HDG) method is reviewed in the context of compressible flows, presenting an original unified framework for the derivation of Riemann solvers in hybridised formulations. The framework includes, for the first time in an HDG context, the HLL and HLLEM Riemann solvers as well as the traditional Lax-Friedrichs and Roe solvers. The positivity preserving properties of HLL-type Riemann solvers are displayed, demonstrating their superiority with respect to Roe in supersonic cases. In addition, HLLEM specifically outstands in the approximation of boundary layers because of its shear preservation, which confers it an increased accuracy with respect to HLL and Lax-Friedrichs.

An extensive set of numerical benchmarks of practical interest is introduced along this study in order to validate both the low and high-order approaches. Different examples of compressible flows in a great variety of regimes, from inviscid to viscous laminar flows, from subsonic to supersonic speeds, are presented to verify the accuracy properties of each of the proposed methodologies and the performance of the introduced Riemann solvers.

Highlighted publication: Vila-Pérez, J., Giacomini, M., Sevilla, R. and Huerta, A.: Hybridisable Discontinuous Galerkin Formulation of Compressible Flows. *Archives of Computational Methods in Engineering* **28**, 753-784 (2021). doi.

Vasiliki Velona defended her PhD thesis *A study on structure recovery and the broadcasting problem* (pdf), supervised by Gabor Lugosi (ICREA and UPF) and Juanjo Rué (**IMTech** and DMAT), on 17 September 2021 within the UPC doctoral program in Applied Mathematics at the FME.
Currently she is a post-doctoral researcher at the Hebrew University of Jerusalem working with Ori Gurel-Gurevich and Ohad Feldheim.

Thesis summary: The thesis contains a study of two problems of combinatorial statistics. The first one is structure-recovering for partial correlation graphs and the second one is the broadcasting problem on certain families of random recursive trees. In a precise language, the structure-recovery problem that we study is the following: given access to individual entries of a covariance matrix S, the objective is to learn the support of the inverse of S (let us denote the inverse by K) using only a small fraction of the entries of S. We call this problem 'structure recovery' since the zero-entries of K define the adjacency matrix of a graph (the so-called *partial correlation graph*). As an example of why this is an important graph to learn, consider that S corresponds to a Gaussian random vector $(X_1, \ldots, X_n)$. Then an entry s_{ij} is zero if and only if X_i and X_j are independent given the rest of the random variables. A series of algorithms is proposed to address the aforementioned question, assuming that our graphs satisfy certain sparsity conditions. The sparsity that is assumed is related to how much our graph resembles a tree; in particular we deal with trees, graphs of two small connected components, and graphs of small treewidth. The proposed algorithms can also be used to estimate K and not only learn the partial correlation graph. Moreover, they can be used to invert any symmetric positive definite matrix since the analysis can be detached from its statistical connection and impact. The motivation for the use of covariance entries is that S might be too large to be stored, as it often happens in statistical settings. In fact, our goal is to learn the partial correlation graph using a sub-quadratic number of queries, since a quadratic time is needed just to write down and store the covariance matrix — this is the starting point for a big part of the literature. The desired complexity bounds are achieved through our analysis.

Moving to the second problem under study, we consider a broadcasting process on a graph to be the propagation of a message (let us say a bit value in $\{0, 1\}$) from one node to all the rest, possibly corrupted. Our goal is to guess the initial message. We consider that our graph is a tree created dynamically at times $0, 1, \ldots, n$, in a way that at time i the i-th vertex enters the system and attaches with an edge to an existing vertex j (we then write $i \sim j$). We are interested in the case where i attaches uniformly at random to an existing vertex (uniform attachment) or where i attaches to a vertex with probability proportional to the outdegree of an existing vertex, plus some parameter $\beta > 0$.

The broadcasting process we consider is one where vertex 0 (the root) has a bit value that is propagated correctly to its neighbours with probability $1-q$ and incorrectly with probability q. The broadcasting problem under study can be formulated in this way: given access to a random tree produced by either uniform attachment or preferential attachment and the bit values of the vertices, but without observing the time labels of the vertices, recover the bit of vertex zero. In a more difficult variant, we answer the same question given only the bits of vertices with outdegree zero (the leaves). In both variants of the problem in both models, we characterize the values of q for which the optimal reconstruction method has a probability of error bounded away from $1/2$. We also show that the probability of error is bounded by a constant times q. Two simple reconstruction rules are analyzed in detail. One of them is the simple majority vote, the other is the bit value of the centroid of the tree (or the closest leaf to the centroid). We also analyze a third reconstruction rule which is more complex but works for all q where reconstruction is theoretically possible.

Highlighted publication: Gábor Lugosi, Jakub Truszkowski, Vasiliki Velona and Piotr Zwiernik. "Learning partial correlation graphs and graphical models by covariance queries", *Journal of Machine Learning Research* **22**, September 2021, 1-41 (pdf).

Marina Garrote López defended her PhD thesis *Algebraic and semi-algebraic phylogenetic reconstruction*, supervised by Professor Marta Casanellas and Professor Jesús Fernández-Sánchez, on 22 July 2021 within the UPC doctoral program in Applied Mathematics. She is currently a postdoctoral researcher in the Nonlinear algebra group of Professor Bernd Sturmfels at the Max Planck Institute for Mathematics in the Sciences in Leipzig. In Spring 2022 she will visit Professor Elizabeth S. Allman and Professor John A. Rhodes at the University of Alaska, Fairbanks. In summer 2022, she will move to University of British Columbia to work as a postdoctoral researcher with Professor Elina Robeva.

Thesis summary. Phylogenetics is the study of the evolutionary history and relationships among groups of biological entities (called taxa). These evolutionary processes are modeled by phylogenetic trees whose nodes represent different taxa and whose branches correspond to the evolutionary processes between them. The leaves symbolize contemporary taxa and the root is their common ancestor. Phylogenetic reconstruction aims to estimate the phylogenetic tree that best explains the evolutionary relationships of current taxa using solely information from their genome. We focus on the reconstruction of the topology of phylogenetic trees, which means reconstructing the shape of the tree considering labels at the leaves.

To this end, one usually assumes that DNA sequences evolve according to a Markov process on a phylogenetic tree ruled by a model of nucleotide substitutions. These substitution models are specified by transition matrices associated to the edges of the tree and by a distribution of nucleotides at the root. Given a tree T, one can compute the distribution of nucleotide patterns at the leaves of T in terms of the parameters of the model. This joint distribution is represented as a vector whose entries can be expressed as polynomials on the model parameters. There exist certain algebraic relationships between the entries of the joint distribution, and the study of them and the geometry of the algebraic varieties that they define (called phylogenetic varieties) have provided further successful results on the problem of phylogenetic reconstruction. However, from a biological perspective we are not interested in the whole variety, but only in points that have arisen on a tree with stochastic parameters. The description of such distributions lead to semi-algebraic constraints and the region of the algebraic varieties defined by them is called the phylogenetic stochastic region. This semi-algebraic description seems important since it characterizes distributions with a biological and probabilistic sense, but could it improve the already existent algebraic tools for phylogenetic reconstruction?

To answer this question, we compute the Euclidean distance of data points to the phylogenetic varieties and their stochastic regions for cases of special interest in phylogenetics, such as trees with short branches in the external edges and with the long branch attraction phenomenon [5]. In some cases, we compute these distances analytically and we can decide which tree has stochastic region closer to the data point. As a consequence, we can prove that, even if the data point was close to the phylogenetic variety of a given tree, it might be closer to the stochastic region of another tree. In particular, under the phenomenon of long branch attraction, considering the stochastic phylogenetic region seems to be fundamental for the phylogenetic reconstruction problem [2].

However, incorporating semi-algebraic tools into phylogenetic reconstruction methods might be extremely difficult and the procedure to do it is not at all evident. In this thesis, we present two phylogenetic reconstruction methods that combine algebraic and semi-algebraic conditions for the general Markov model, based on the result proved in [1]. The first method we present is SAQ, which stands for Semi-Algebraic Quartet reconstruction method [3]. Next, we introduce an improved method, ASAQ (for Algebraic and Semi-Algebraic Quartet reconstruction method, [4]), which combines SAQ with the method Erik+2 (based on certain algebraic constraints). Both are phylogenetic reconstruction methods for DNA alignments on four taxa and have been proven to be statistically consistent.

We test the proposed methods on simulated and real data to check their actual performance in several scenarios, both consistent and violating the assumptions of the methods. Our results show that both methods SAQ and ASAQ are highly successful, even with short alignments and with data that violates their assumptions.

Highlighted publicacion: [2].

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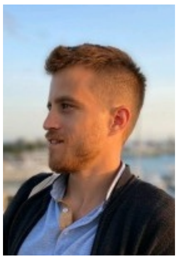
David Codony defended his PhD thesis *Mathematical and computational modeling of flexoelectricity at mesoscopic and atomistic scales* (pdf) on March 1st 2021, supervised by Professor Irene Arias in the Mechanics of Electroactive Materials research group in LaCàN, within the UPC doctoral program in Applied Mathematics. During his doctoral training he also joined the MP&M group in Georgia Tech (Atlanta, GA, USA) lead by Professor Phanish Suryanarayana as a visiting scholar for 5 months. He is currently a Severo Ochoa postdoctoral trainee in the group of Mechanics of Electroactive Materials at CIMNE, and part-time associate professor at UPC.



Thesis summary. Flexoelectricity is the two-way coupling between polarization and strain gradients. Conversely, it couples also polarization gradients and strain. It has emerged as an alternative to piezoelectricity at small scales. Piezoelectricity, the linear coupling between polarization and strain, is limited by symmetry and thus sustained only by materials with a non-centrosymmetric atomic or molecular structure. This introduces limiting tradeoffs regarding performance, toughness, toxicity or operating temperature. For instance, current electromechanical transduction technologies in sensors, actuators and energy harvesters widely across industries rely strongly on piezoelectric ceramics such as PZT, with high contents of toxic lead. Being a universal property of all dielectrics, flexoelectricity broadens the class of materials for electromechanical transduction at small scales, where gradients are sufficiently large. Hence, it has the potential to become a key mechanism for cleaner and safer energy devices [1].

Harnessing flexoelectricity as a functional property requires complex gradient-generating geometries with sub/micron features, calling for advanced modeling and computational tools which were not available just a few years back. In this PhD thesis, we develop an advanced computational infrastructure to quantify flexoelectricity in solids, focusing on continuum models but also exploring multiscale aspects.

On the one hand, we develop a mathematical and computational model for flexoelectricity at the continuum level. Mathematically, flexoelectricity is modeled as a coupled system of fourth-order PDEs. The high-order nature of the problem in combination with designs spaces necessarily involving complex geometries, calls for advanced computational techniques beyond standard finite element methods. This novel computational infrastructure is able to predict the performance of engineered devices for electromechanical transduction at sub-micron scales, where flexoelectricity is always present, without any particular restriction in geometry, material choice, boundary conditions or nonlinearity [2-4]. It is used to explore different means to harness flexoelectricity towards the development of breakthrough applications in nanotechnology [5]. Of particular interest is the design of flexoelectricity-based metamaterials producing a significant piezoelectric-like response from non-piezoelectric base-materials [6]. These metamaterials open up the way for light-weight chemically and mechanically biocompatible electromechanical devices.

On the other hand, we also explore flexoelectricity form first principles and establish the connection between the continuum and the atomistic description. We propose a novel methodology to quantify the flexoelectric properties of dielectric materials [7] by connecting the proper interpretation of ab-initio atomistic simulations with the proposed models at a coarser, continuum scales. The developed approach sheds light on a controversial topic within the density functional theory community, where large disagreements among different theoretical derivations are typically found. The ab-initio computations serve not only to extract material parameters for the continuum models [8], but also to validate their inherent assumptions regarding the relevant physics at the nanoscale.

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Xavier Rivas Guijarro defended his PhD thesis *Geometrical Aspects of Contact Mechanical Systems and Field Theories* (pdf) on December 17th, 2021. The thesis was produced within the UPC doctoral program in Applied Mathematics and was supervised by Professors Xavier Gràcia Sabaté and Narciso Román Roy.

Thesis summary: Many important theories in modern physics can be stated using the tools of differential geometry. It is well known that symplectic geometry is the natural framework to deal with autonomous Hamiltonian mechanics. This admits several generalizations for nonautonomous systems and classical field theories, both regular and singular. Some of these generalizations are the subject of the present dissertation.

In recent years there has been a growing interest in studying dissipative mechanical systems from a geometric perspective by using contact structures. In the present thesis we review what has been done in this topic and go deeper, studying symmetries and dissipated quantities of contact systems [2], and developing the Lagrangian-Hamiltonian mixed formalism (Skinner–Rusk formalism) for these systems [5].

With regard to classical field theory, we introduce the notion of k-precosymplectic manifold and use it to give a geometric description of singular nonautonomous field theories. We also devise a constraint algorithm for k-precosymplectic systems [1].

Furthermore, field theories with damping are described through a modification of the De Donder–Weyl Hamiltonian field theory [3]. This is achieved by combining both contact geometry and k-symplectic structures, resulting in what we call the k-contact formalism. We also introduce two notions of dissipation laws, generalizing the concept of dissipated quantity. The preceding developments are also applied to Lagrangian field theory [4]. The Skinner–Rusk formulation for k-contact systems is described in full detail and we show how to recover both the Lagrangian and Hamiltonian formalisms from it [6].

Throughout the thesis we have worked out several examples both in mechanics and field theory. The most remarkable mechanical examples are the damped harmonic oscillator, the motion in a constant gravitational field with friction, the parachute equation and the damped simple pendulum. On the other hand, in field theory, we have studied the damped vibrating string, the Burgers' equation, the Klein–Gordon equation and its relation with the telegrapher's equation, and the Maxwell's equations of electromagnetism with dissipation.

Highlighted publication: [3]

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Outreach

Quantum Error-Correction,

by Simeon Ball.

Received October 14th, 2021.

Classical error-correction is the process by which data is protected from being corrupted by noise. In its simplest form we wish to protect a sequence of zeros and ones which are either being stored or transmitted. A repetition code gives a simple protection against a bit flip error in which a 0 flips to a 1 and vice-versa. To employ this code, instead of sending a 0 we send three zeros, 000, and instead of a 1 we send three ones, 111. Thus, to send the message 00110 we would send 000000111111000. On receipt, we make a majority decision on each block of three bits. In other words, if a block of three bits is 000, 001, 010 or 100 then, since the majority of the bits are zero, we suppose that 000 was sent and decode as 0. In this way, the sequence 001000110111001 is decoded as 00110. Even though three bit flips occurred we still managed to recover the initial data. Thus, we have seen a simple way to recover our data as long as no more than one in every sequence of three bits is flipped. Unfortunately we have to send three bits for every one bit of information. If we have a particularly noisy channel then we must send even more bits per bit of information. One can do better by using more sophisticated codes. The Hamming code encodes four bits onto seven bits and is able to correct one bit flip in every sequence of seven bits. Note that the rate of the repetition code above was $\frac{1}{3}$ whereas the Hamming code is $\frac{4}{7}$ which is a vast improvement. Finding codes with high rate which are robust enough to allow us to detect and correct errors is a central problem of classical error-correction.

Quantum error-correction is the process by which a quantum state is protected from being corrupted by noise. Noise is a significant problem in quantum computation since, by their very nature, quantum states are unstable and liable to interference from the surrounding environment. A quantum state is usually denoted by $|\psi\rangle$, a column vector of the complex vector space $(\mathbb{C}^2)^{\otimes n}$. The parameter n is the number of quantum particles in the system we are considering. If we have an 80 qubit quantum computer then $n = 80$. The reason we have $\mathbb{C}^2$ is that we are assuming the individual quantum particles will be in one of two states, usually denoted by $|0\rangle$ and $|1\rangle$, upon measurement. This measurement may be simply observation. The $|0\rangle$ and $|1\rangle$ are column vectors of $\mathbb{C}^2$ and form an orthonormal basis of this vector space. A particle exhibiting quantum properties can be in a superposition of these states. Thus, a single qubit can be in a state

$$|\psi\rangle = a|0\rangle + b|1\rangle \in \mathbb{C}^2.$$

For example, a photon, after passing through a beam splitter, maybe in the state $\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$, where $|0\rangle$ corresponds to the horizontal direction and $|1\rangle$ to the vertical direction. Upon observation, the particle will be in $|0\rangle$ or $|1\rangle$. One interpretation of the state $|\psi\rangle$ is that it will be in $|0\rangle$ with a probability $a\bar{a}$ and $|1\rangle$ with a probability $b\bar{b}$. Here, $\bar{z}$ is the complex conjugate of the complex number z. Since probabilities must sum to 1, we have that $a\bar{a} + b\bar{b} = 1$. Thus, the quantum state of a single particle is described by a unit vector in $\mathbb{C}^2$ and more generally the quantum state of a system of n particles is described by a unit vector in $(\mathbb{C}^2)^{\otimes n}$. We generally use the orthonormal basis

$$\{|x_1 x_2 \dots x_n\rangle \mid x_i \in \{0,1\}\}$$

for the vector space $(\mathbb{C}^2)^{\otimes n}$.

A more surprising property than superposition is that quantum particles can become entangled. Consider the state of a system of two quantum particles

$$\tfrac{1}{\sqrt{2}}(|00\rangle + |11\rangle).$$

If the first particle is observed to be in state $|0\rangle$ then second particle will necessarily be in state $|0\rangle$, since the coefficient of $|01\rangle$ is zero and thus there is no chance that the second particle will be found in state $|1\rangle$. That is, the particles are entangled. Entanglement is a very useful property; quantum error-correction relies on entanglement.

As in classical error-correction, where we encode k bits of data with n bits, one encodes k qubits of information onto n qubits. The image of this map is a k-dimensional subspace Q of $(\mathbb{C}^2)^{\otimes n}$ which is our quantum error-correcting code. Changes to the state $|\psi\rangle$ of the quantum system are given by unitary linear transformations. Consider, for the moment, just one particle. The linear transformations of $\mathbb{C}^2$ are given by 2×2 matrices, which as a vector space is 4-dimensional. Thus, an error in one particle is a unitary linear transformation which is a linear combination of 4 linearly independent matrices. A convenient basis for this space of matrices is the set of Pauli matrices,

$$\mathbb{1} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix},\ X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix},\ Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix},\ Y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}.$$

One major theorem of quantum error-correction states that if one can correct a set $\mathcal{E}$ of errors then one can correct all errors in the span of matrices of $\mathcal{E}$, [1, Theorem 10.2].

For any $|\psi\rangle$, we denote by $\langle\psi|$ the corresponding row vector whose coordinates have been conjugated. Thus, $\langle\phi|\psi\rangle$ is the standard inner product on the complex space. The other major theorem of quantum error-correction tells us precisely the property that Q should have so that there exists a recovery map that allows us to recover $|\psi\rangle \in Q$, after the noisy error operator has been applied to $|\psi\rangle$. To be able to correct all errors in a set $\mathcal{E}$, and therefore all linear combinations of errors in $\mathcal{E}$, it suffices that

$$\langle\phi|E_i^\dagger E_j|\psi\rangle = c_{ij}\langle\phi|\psi\rangle, \tag{1}$$

for any errors $E_i, E_j \in \mathcal{E}$ and for all $|\psi\rangle, |\phi\rangle \in Q$.

The essential observation here is that orthogonal states of Q remain orthogonal after the errors are applied to them.

What kind of errors are we trying to correct? In classical error-correction we try to correct small weight errors, i.e. errors which have a small number of bit flips. The same is true of quantum errors. The Pauli operators are of the form

$$\sigma_1 \otimes \sigma_2 \otimes \cdots \otimes \sigma_n,$$

where $\sigma_i \in \{\mathbb{1}, X, Y, Z\}$. We typically expect $\mathcal{E}$ to contain all tensor products where most of the σ_i are the 2×2 identity matrix $\mathbb{1}$ and just a few are one of the other Pauli matrices.

How do we find a quantum error-correcting code Q? Most known constructions are stabiliser codes, so named because Q is stabilised by a large set S of Pauli operators. The set S is chosen to be an abelian subgroup of the multiplicative group of Pauli operators. Observe that since $Y = iXZ$ and the Pauli matrices either commute or anti-commute, the set of Pauli operators becomes a multiplicative group if we allow ourselves to scale by ± 1 and $\pm i$. The code

$$Q = \{|\psi\rangle \in (\mathbb{C}^2)^{\otimes n} \mid M|\psi\rangle = |\psi\rangle, \text{ for all } M \in S\}$$

Now we can check that we can correct all errors E that are not in the centraliser of S. Since E is not in the centraliser of S, there is an $M \in S$ such that $EM = cME$, $c \neq 1$. Then, for all $|\psi\rangle, |\phi\rangle \in Q$,

$$\langle\psi|E|\phi\rangle = \langle\psi|EM|\phi\rangle = c\langle\psi|ME|\phi\rangle = c\langle\psi|E|\phi\rangle$$

from which it follows that $\langle\psi|E|\phi\rangle = 0$, Thus, the condition (1) is satisfied for all $E_i^\dagger E_j$. Therefore, we only need find abelian subgroups S for which the centraliser of S has no small weight Pauli operators.

Let us summarise the quantum error-correction process. We store quantum information on k qubits on a state $|\psi\rangle$ which is a vector in a k-dimensional error-correcting code Q. We have a recovery map which will map $E|\psi\rangle$ to $|\psi\rangle$ for any linear combination of small weight Pauli operators E. We will wish to process the information, that is apply some unitary transformation to the state $|\psi\rangle$. This must be done fault-tolerantly. That is, we must apply logic gates designed according to Q, so that the probability that a large weight error occurs is arbitrarily small. The design of fault tolerant logic gates is another interesting aspect of quantum error-correction. Finally, after the computation is complete, we measure the quantum state to learn the result of the computation. Details of the known quantum algorithms can be found in Chapters 5 and 6 of [1]. The design of quantum algorithms is yet another interesting branch of quantum computation. For more details on this and all of the above see [1].

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Data Analytics for efficient healthcare systems,

by Ricard Gavaldà, Amalfi Analytics (On leave from UPC).

Received October 19th, 2021.

The context. Europe and the developed world are aging quickly. About 23% of the Europeans are over 65 today, and estimates are that this percentage will be 40% by 2040. This puts an enormous stress on the pillars of the welfare state, in particular retirement pensions, social services for the elderly, and healthcare. Given that healthcare already uses about 20% of public spending, large increases in funding are unlikely.

The panorama is dismal, but there is one hope: There are huge inefficiencies in the healthcare system, and so opportunities for getting more from the same resources. Avoidable hospitalizations, unnecessary medication and tests, and lack of coordination among healthcare agents are estimated to cost several hundred billion euros yearly in the EU.

The Case for Activity Data Analytics. Technology can be useful for locating and reducing these inefficiencies and, within technology, the full exploitation of the data that the system collects to record its activity.

Amalfi Analytics is a spinoff of the UPC. It originated when the author of this note, a pure academic doing research on Machine Learning, meets medical Dr. Julianna Ribera. Julianna's 30+ year career includes many management positions in the Catalan healthcare services, in hospitals, primary care, and planning at the territorial level. She felt that people that are in charge of managing healthcare, with a clinical view but also aware of resource constraints, did not have the adequate tools.

Amalfi wants to provide the managers with the data analytic tools that Julianna always wanted to have as a manager, to predict needs, anticipate demands, and allocate resources accordingly.

Discovering insights in clinical healthcare records. Consider the ANIS platform we have developed for analyzing clinical healthcare records. It focuses on improving attention to patients with chronic diseases. It receives the activity data that hospitals use for billing the government or insurance companies. For each visit to the healthcare provider, it contains date, basic patient data and diagnostics and treatments, all in standardized codes.

This information is certainly too basic to do precision medicine or personalized diagnosis. But, one, the hospital is already extracting it, and two, it describes population health status accurately enough to decide on health policies, attention protocols, and planning.

For example, ANIS contains a powerful clustering algorithm derived from Matteo Ruffini's Ph.D. thesis [1,2]. It can partition the set of patients of a given pathology into clear subgroups with distinct comorbidities, treatments, medication, and clinical results. Then, instead of treating all these patients uniformly with a single clinical guideline, clinicians can decide to adapt the protocols to specific subgroups and route patients differently within the system. We have seen that this invariably leads to both reduced costs for the system and increased patient safety.

Critical to the practical success of this approach are the special features of the clustering algorithm. It is based on tensor decomposition techniques and maximizing the likelihood of the data given the clusters. It tends to find more interesting structure in high-dimensional data as is our case. It is not distracted by irrelevant variables. And it does not require an explicit "similarity" or "distance" function to work; we cannot expect a clinician to define such a function when starting a study.

ANIS contains other features such as algorithms for efficiently mining k-ary associations among diagnostics [3].

We find specially gratifying that the algorithms above all have rigorous mathematical guarantees of performance *and* work well in practice. They are fast and, most of the time, they provide interesting insights to clinicians that use them.

Predictive tools for managing resources. While ANIS is designed for occasional, in-depth analysis, other platforms developed at **Amalfi** are designed for daily routine use at various parts of the healthcare system.

For example, Emergency Rooms (ER) are one of the hot spots in any hospital. The APIS platform uses historical activity data (plus other data) to train predictive models of activity. It predicts the influx to the ER (how many people will arrive, and with what kind of problems), how many people will occupy each space of the ER, and how many of these patients will have to be hospitalized, with time horizons ranging from hours to weeks. This lets the manager anticipate peaks of activity and congestion, and rearrange staff and resources before chaos occurs.

A major challenge in these platforms is the robustness and autonomy of the predictive models or, in other words, the fact that the distribution of the data arriving in the system is anything but stationary. Some changes occur gradually (e.g. aging population), but others occur suddenly (e.g., the hospital changes some protocol, or COVID-19 explodes). The platform needs to be continuously checking for changes, revising parts of the model, or throwing away the existing model altogether and creating a new one. Here the tool has been the algorithmics of machine learning on data streams [4].

In conclusion. There are innumerable problems in healthcare management, large and small, that can benefit from good Machine Learning / data analytic algorithms. Imagination for matching healthcare problems to algorithms is crucial. But if these algorithms are to be deployed in hospitals without continuous supervision by a data scientist, the strengths and limitations of algorithms should be well understood mathematically — something that we feel is still lacking in much of Deep Learning, for example.

Given the highly sensitive nature of healthcare data and the necessary legal restrictions, we are at the moment interested in the practicality of two research areas: Federated Learning, that allows learning from separate sources of data without exchanging them, and Differential Privacy, to do Machine Learning on encrypted, unidentifiable data.

Both are still largely untested in healthcare setting (in fact in any practical setting). We already have a working implementation of a Federated Learning framework.

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Chronicles

The European Conference on Combinatorics, Graph Theory and Applications (Eurocomb'21) at UPC
by Guillem Perarnau and Juanjo Rué (DMAT & **IMTech**, Chairs of the Organizing Commitee of Eurocomb'21)

In the year 2001, Barcelona was the first host site of the European Conference on Combinatorics, Graph Theory and Applications (Eurocomb). After 20 years, its 11th edition has come back to our city, being fully organized by UPC. In previous years, Eurocomb has taken place in different european cities: Prague, Berlin, Seville, Bordeaux, Budapest, Pisa, Bergen, Vienna and Bratislava. This year has been special due to the extraordinary situation concerning COVID: it was the first time this conference has been organized fully online. All details concerning its organization can be found in the website of the conference: Eurocomb'21. The event was sponsored by CUP, CRM, DIMATIA, Elsevier, IEC, SCM, and of course UPC.

The conference was a showcase of the most recent advances in Combinatorics and Graph Theory including applications in other areas of Mathematics, Computer Science and Engineering. The list of topics included is Algebraic Combinatorics, Combinatorial Geometry, Combinatorial Number Theory, Combinatorial Optimization, Designs and Configurations, Enumerative Combinatorics, Extremal Combinatorics, Graph Theory, Ordered Sets, Probabilistic Combinatorics, Random discrete structures and Topological Combinatorics.

There were 10 plenary lectures by world-leading researchers in the area of Discrete Mathematics and also in related fields such as Theoretical Computer Science: Julia Böttcher (LSE, London), Josep Díaz (UPC, Barcelona), Louis Esperet (G-SCOP, Grenoble), Christian Krattenthaler (U. Wien), Sergey Norin (McGill, Montreal), Will Perkins (UIC, Chicago), Marcin Pilipczuk (U. of Warsaw), Lisa Sauerman (MIT), Eva Tardos (Cornell, Ithaca), and David Wood (Monash, Melbourne). The conference had 273 participants, a notable increase with respect to the 170 participants of the 2019 edition. Among them, 119 were students (44 %). From the usage perspective there were a total of 2760 connections, 131353 Minutes of streaming (this is equivalent to 3 months), 138 average participants at each plenary lecture and 47 average participants at each contributed session... all that data in a 5 day conference!

There were a total of 178 submissions, from which 135 were accepted for a contributed talk, that were split into 4 parallel sessions. The accepted extended abstracts have been published as a volume of CRM Research Perspectives by Birkhäuser (858 pages), edited by Jaroslav Nesetril, Guillem Perarnau, Juanjo Rué and Oriol Serra.

Two special events were held during the conference. Firstly, the prestigious European Prize in Combinatorics 2021 was awarded. This prize, which started at EUROCOMB 2003, awards significant contributions to combinatorics and related areas to researchers who are not older than 35 years and are either European citizens or employed by a European university. At EUROCOMB'21 the international jury consisted from Prof. Béla Bollobás (University of Cambridge and The University of Memphis), Prof. Jaroslav Nesetril (chair, Charles University, Prague), and Prof. János Pach (Alfréd Rényi Institute of Mathematics, Budapest). The jury decided to award four prizes. In alphabetical order, the four laureates were: Péter Pál Pach (Budapest University of Technology and Economics), Julian Sahasrabudhe (University of Cambridge), Lisa Sauermann (MIT), and Istvan Tomon (ETH Zürich). The prize cerimony took place at the main building of the Institut d'Estudis Catalans (IEC), and was hosted by the President of Societat Catalana de Matemàtiques, Prof. Dolors Herbera, and with the participation of the Research Vicerrector at UPC, Prof. Jordi Llorca, and Director of Centre de Recerca Matemàtica, Prof. Lluis Alsedà. Secondly, there was a special session of the conference devoted to the memory of Prof. Robin Thomas and his contributions in Combinatorics. The session included the plenary lecture by Sergey Norin and invited talks by Dan Král', Zdenek Dvorak, and Luke Postle.

There was an international programme committee formed by Maria Axenovich (KIT, Karlsruhe), Agnes Backhausz (Eötvös Loránd U., Budapest), Marthe Bonamy (LABRI, Bordeaux), Michael Drmota (TUWien), Zdenek Dvorák (Charles University, Prague), Stefan Felsner (TU Berlin), Ervin Gyori (Alfred Rényi Institute, Budapest), Dan Král' (Masaryk University, Brno), Bojan Mohar (SFU, Vancouver and Univ. of Ljubljana), Rob Morris (IMPA, Rio de Janeiro), Jaroslav Nešetril (Charles University and ITI, Prague), Chair, Marc Noy (UPC, Barcelona), Patrice Ossona de Mendez (CNRS and EHESS, Paris), Marco Pellegrini (IIT-CNR, Pisa), Oleg Pikhurko (Warwick), Andrzej Rucinski (UAM, Póznan and Emory), Oriol Serra (UPC, Barcelona), Co-chair, Martin Skoviera (Comenius U., Bratislava), Jozef Skokan (LSE, London), Maya Stein (U. de Chile, Santiago de Chile), Benjamin Sudakov (ETH, Zurich) and Xuding Zhu (Zhejiang Normal U., Jinhua).

Finally, but not least, the local organizing committee was mostly composed of researchers from UPC. The complete list of organisers is Albert Atserias (UPC), Simeon Ball (UPC), Ilario Bonacina (UPC), Matthew Coulson (UPC), Anna de Mier (UPC), Alberto Espuny (Ilmenau), Guillem Perarnau (UPC), co-chair, Clément Requilé (Uppsala), Juanjo Rué (UPC), co-chair, Christoph Spiegel (Zuse Institute, Berlin), Vasiliki Velona (UPC and UPF), Lluís Vena (UPC) and Maximilian Wötzel (UPC). We warmly thank all of them for their commitment and support to the organization of this successful event.

The ICIAM 2019 SEMA SIMAI Springer Series, by Amadeu Delshams (**IMTech**), Editor in Chief (EiC) of the series.

During the third week of July the ICIAM 2019 Congress took place in Valencia with almost 4,000 participants, 50 plenary lectures, more than 300 mini-symposia, 550 contributed talks and 250 posters. A wide representation of the world of applied mathematics met in Valencia to present and discuss how mathematics was applied to the most diverse disciplines, such as:

- Applied Mathematics for Industry and Engineering.
- Biology, Medicine and other natural sciences.
- Control and Systems Theory.
- Dynamical Systems and Nonlinear Analysis.
- Finance and Management Science.
- Industrial Mathematics.
- Mathematics and Computer Science.
- Numerical Analysis.
- Partial Differential Equations.
- Simulation and Modelling.

Within the organizing committee the idea arose that it would be very convenient to capture a significant part of the presentations and debates that took place. After several contacts with the Springer publishing house, this idea gave rise to a series of volumes that would record the most outstanding advances that took place in it.

This offer crystallized in the ICIAM 2019 SEMA SIMAI Springer Series, which included several volumes. Among them, the volume dedicated to the lectures of the plenary speakers, which occupies a very central and special place, as it is offered in open access mode, thanks to the support of SEMA (Sociedad Española de Matemática Aplicada).

The selection of the 336 mini symposia of the ICIAM 2019 was made by its Academic Committee. In a very direct relationship, the Editorial Committee of this series was formed by A. Delshams (EiC), F. Arándiga Llaudés, M. M. Gómez Mármol, F. M. Guillén-González, F. Ortegón Gallego, Carlos Parés, P. Quintela, C. Vázquez-Cendón, S. Xambó-Descamps.

The members of this Committee were in charge of selecting the proposals, many of them derived from mini-congress symposia, and also of acting as editors in charge of the 13 volumes that make up this series:

- Recent advances in Industrial and Applied Mathematics, edited by Tomás Chacón Rebollo, Rosa Donat and Inmaculada Higueras.
- Mathematical Descriptions of Traffic Flow: Micro, Macro and Kinetic Models, edited by Gabriella Puppo and Andrea Tosin.
- Systems, Patterns and Data Engineering with Geometric Calculi, edited by Sebastià Xambó-Descamps.
- Multidisciplinary Mathematical Modelling. Applications of Mathematics to the Real World, edited by Francesc Font Martínez and Tim Myers.
- Progress in Industrial Mathematics: Success Stories, edited by Manuel Cruz, Carlos Parés and Peregrina Quintela.
- Improving Applied Mathematics Education, edited by Ron Buckmire and Jessica M. Libertini.
- Fractals in engineering: Theoretical Aspects and Numerical Approximations, edited by Maria Rosaria Lancia and Anna Rozanova-Pierrat.
- Recent Advances in Differential Equations and Control Theory, edited by Carmen Pérez-Martínez and Concepción Muriel.
- Applications of Wavelet Multiresolution Analysis, edited by Juan Pablo Muszkats, Silvia Alejandra Seminara and María Inés Troparevsky.
- Stabilization of Distributed Parameter Systems: Design Methods and Applications, edited by Grigory Sklyar and Alexander Zuyev.
- Applied Mathematics for Environmental Problems, edited by María Isabel Asensio, Albert Oliver Serra and José Sarrate.
- Cartesian CFD Methods for Complex Applications, edited by Ralf Deiterding, Margarete Oliveira and Kai Schneider.
- Emerging problems in the Homogenization of Partial Differential Equations, edited by Patrizia Donato and Manuel Luna-Laynez.

As can be easily seen, the application of mathematics spreads through the most diverse areas such as Industry, Health and

Energy, Engineering Data Science, Environmental problems, Geometric Calculi, Numerical approximation, Traffic flow, Education, etc.

I encourage the reader to delve into the volumes of this series and to learn, reflect, incorporate new ideas and, in general, enjoy its content, with the hope that the volumes of this series can serve as a reference for even more innovative applications of mathematics in the future.

This series has been made possible by many people. Starting with the 2019 ICIAM Congress, especially its Executive Committee led by Tomás Chacón and Rosa Donat as living forces of the event, as well as its scientific committee led by Alfio Quarteroni and the multiple organizers of mini-symposia, speakers and attendees. Continuing with Francesca Bonadei as a promoter within Springer of the need for the existence of this series, and ending with the responsible editors and authors of each volume, who, with their excellent work, are the real creators of the message of this series.

IMTech Colloquium 24/11/2021
by Gemma Huguet

On November 24, Professor Lai-Sang Young delivered an IMTech Colloquium Lecture on *Chaotic and random dynamical systems*

Since 1999, L-S Young holds the Henry & Lucy Moses Professorship of Science and is professor of mathematics and neural science at the NYU Courant Institute of Mathematical Sciences. She earned her PhD (1978) from the University of California at Berkeley. In the past, she held positions at Northwestern University, Michigan State University, the University of Arizona, and the University of California, Los Angeles. She is currently distinguished visiting Professor at the Institute for Advanced Study. In 2020 she was elected a member of the National Academy of Sciences.

She is an outstanding scientist for her contributions to the field of Dynamical systems, and in particular chaotic systems. In the last 10-15 years, she expanded her research to large and complex dynamical systems and in particular to Theoretical and Computational Neuroscience, where she has important contributions.

In her lecture she compared and contrasted chaotic (deterministic) dynamical systems with their stochastic counterparts, that is, when small random perturbations are added to model uncontrolled fluctuations. She organized the presentation in 3 parts. In the first part, she discussed how deterministic systems that are sufficiently chaotic produce signals that resemble (genuinely random) stochastic processes. In the second part, she compared the ergodic theories of chaotic systems and of random maps (such as stochastic flows generated by Stochastic Differential Equations), showing that many results are nicer in the random category. In the last part, she showed that in some ways existing theory of chaotic systems requires too detailed information for it to be readily applicable, while a little bit of random noise can go a long way.

CRM awarded *Maria de Maeztu* insignia, by Marcel Guàrdia* and Eva Miranda*,**. *Received Novembre 3rd, 2021.*
* DMAT, **IMTech** and CRM. ** Director of the LGSD.

The CRM (Centre de Recerca Matemàtica) has recently been awarded the accreditation as ***María de Maeztu*** Unit of Excellence for the period 2022-2025 (2020 call).

The aim of the Spanish ***Severo Ochoa*** and ***María de Maeztu*** programs is to recognise public research organizations, in any scientific area, that stand out on account of the relevance and impact of the results obtained during the previous reference period at an international level. The distinctive is granted after a rigorous evaluation process by an international committee of world-class scientists and according to the most demanding standards. The 2020 call has recognized seven ***Severo Ochoa*** centers of excellence and six **María de Maeztu** excellence units.

The ***María de Maeztu*** award provides funding (2M €) for the proposed CRM strategic research plan, which aims at consolidating the CRM scientific capacities and boosting its capacity to attract talent for the next four years. In particular, this funding will allow the CRM to open 8 predoctoral positions and 15 postdoctoral positions in different research fields within the realm of Mathematics. The CRM will also open 2 junior researcher positions in Artificial Intelligence and Mathematical Modeling in Public Health.

This ***María de Maeztu*** accreditation has been obtained in a moment of deep transformation of the CRM. Indeed, in the last two years several researchers of the UPC and the UAB have become affiliated members of the CRM. These transformations enlarge the research scope of the CRM and strengthens the Catalan mathematical community by fostering interactions between researchers of different fields, ranging from the most theoretical to the most applied ones. The strategic plan of the CRM charts initiatives towards promoting interdisciplinary research both within Mathematics and also with other sciences. These initiatives will be spelled out in the kick off meeting of the ***María de Maeztu*** accreditation which will take place on January 28, 2022, in the CRM facilities.

This is the second time that the CRM has been bestowed with this distinction. The first was on the occasion of launching in 2015 the BGSMath (Barcelona Graduate School of Mathematics), of which the CRM is the managing institution.

The CRM has also joined the SOMMa Alliance, whose goal is to internationally promote, strengthen and maximise the value of the ground-breaking research produced by the Spanish ***Severo Ochoa*** Centres and ***María de Maeztu*** Units of Excellence and the scientific, social and economic impact it generates. There are currently four Mathematical Research Centers in the SOMMa Alliance: ICMAT, BCAM and IMAG (Instituto de Matemáticas de la Universidad de Granada), that has obtained the accreditation as ***María de Maeztu*** Unit of Excellence at the same time as the CRM.

Imaginary, a mathematical symphony,
by Maria Alberich (DMAT & **IMTech**) and S. Xambó.

From 22 September to 17 December 2021, **Imaginary, a mathematical symphony** was exhibited at the FME. Based on the traveling version RSME-Imaginary, which was promoted by the RSME on the occasion of celebrating its centenary in 2011, this time it was extended with four special units on:

1. *The scientific design of musical instruments*;
2. *Robotics*;
3. *Artificial Intelligence*; and
4. *Kaleidoscopic generation of polyhedra*.

They will be described in more detail below.

The original Imaginary exhibition was initiated in 2008 by the MFO, promoted by Gert-Martin Greuel and Andreas Matt, on the occasion of the German Year of Mathematics. RSME-Imaginary is an adaptation of that exhibition. Although the plastic elements (paintings and sculptures) are the same, the texts that accompany the images are not translations of the MFO Imaginary texts, but were written in order to connect with as broad a public as possible, especially secondary school students.

The early promoters of RSME-Imaginary were the then President of the RSME, Antonio Campillo, and Sebastià Xambó, the General Commissioner (2011-2013) of the exhibit. Initially two versions were produced, both with the title “Imaginary: una mirada matemática”: one, based on just 12 images, was displayed in 2011 by CosmoCaixa (six months in Madrid and the next six in Barcelona), and another, the complete travelling exhibition, that in its first period was displayed in fifteen cities in Spain. The latter is based on 31 images of algebraic surfaces with singularities and 13 images of differentiable surfaces. Each image is accompanied by a text. The thread of the texts highlights the interrelation of mathematics with the arts, sciences and technology. The exhibition is eminently interactive. Visitors can experiment with various freely available programs, including Surfer, Mornaments, j-Reality, and a Cinderella kiosk.

The new texts that accompany the images of algebraic surfaces, created by a team coordinated by M. Alberich, were incorporated into the Surfer program by the MFO, thus becoming part of the travelling exhibit of MFO and also of the online exhibition Mathematics of Planet Earth 2013 (MPE2013), promoted by UNESCO.

Sponsored by the Leibniz Association, Imaginary has recently become a non-profit international organization based in Berlin. It is independent of MFO and has representations in several countries. In Spain it is steered by the Imaginary Committee of the RSME, with Julio Bernués as its General Commissioner.

The full itinerant RSME-Imaginary was exhibited during the spring of 2012 in Barcelona, in the Santa Agata chapel of the MUHBA, the City History Museum, under the title *Imaginary/BCN, la mirada matemàtica, les arts i el patrimoni* (the mathematical view, the arts and the heritage). The exhibition of MUHBA incorporated four additional modules stemming from the mathematical look on heritage elements of the city: the wall paintings of Ferrer Bassa (1285-1348) in the Monastery of Pedralbes, the gothic architecture (Santa Agata, Tinell, and the Monastery of Pedralbes), and the clock that clanged quarters and hours to the city between 1577 and 1864 (the Flemish clock). It also included a fourth module dedicated to Esteban Terradas (1883-1950) in recognition of his wide and penetrating mathematical and engineering mind. The four local modules were the result of an intense and fruitful collaboration between MUHBA and teams of UPC professors headed by M. Alberich (Gothic painting), Joan Font (Gothic Architecture), Joaquim Agulló Batlle (clock) and Antoni Roca Rosell (Terradas).

After ten years, the RSME-Imaginary has visited the FME on the occasion of the 50th anniversary of the UPC, now with the title ***Imaginary, a mathematical symphony***, which is meant to evoke that a “mathematical melody” is emitted not only by music, but also by art, science, engineering, and the humanities. The space ***Fiction Sciences: Art, Machines, and Algorithms***, which is the specific addition by the FME to the exhibition, facilitates tuning to that melody. It consists of four units, respectively devoted to the scientific design of musical instruments (highlighting the creation of a new musical instrument, the ‘barítona’ in Catalan), robotics (with special mention of their applications to surgery and healthcare), artificial intelligence, and two deltoidal kaleidoscopes provided by the Mathematics Museum of Catalonia (MMACA) that generate images, through reflections of a set of carefully crafted pieces, of the Archimedean polyhedra and their duals.

Each unit was introduced by two computer-generated graphics and two text panels, all designed according to the standard format of RSME-Imaginary. Thus the four introductions were meant to appear as a prolongation of that exhibit, but pointing to the modules within the ***Fiction sciences***. The first three modules consisted of two graphics-and-text panels, providing more detail about the contents of the module, and a high resolution TV screen displaying an interactive menu that provided access to a variety of experiences, especially videos. In the case of the MMACA module, each kaleidoscope had an associated panel featuring the polyhedra that it could generate. It had also a collection of colorful polyhedra built by folding paper.

The production of the ***Fiction Sciences*** has been possible thanks to the collaboration of many researchers from UPC and from institutions in the UPC ecosystem. They have shared their research results, have granted permission for their use, and have been involved in the work of popular dissemination. In addition to the names in this list of collaborations, there were many others that contributed anonymously. Concerning the production of the displayed contents, a special acknowledgement is due to the following names. ‘Barítona’ unit: Joaquim Agulló, Maria Alberich, Sebastià Xambó and Jordi Campos; Robotics unit: Maria Alberich, Pablo Jiménez, Sebastià Xambó, with advice from Alícia Casals and Carme Torras; AI unit: Karina Gibert, Sebastià Xambó, Cristian Barrué, Ulises Cortés, Diana F. Vélez; MMACA unit: Josep Rey, Manuel Udina, and Sebastià Xambó. Let us also mention the research institutions to which collaborators are affiliated: IRI, CREB, BSC, IEC, IDEAI, and **IMTech**

The initiative was rewarded by the visit of over 800 people in 25 guided tours. There were also an unknown number of visitors that did not request a guide. On December 1st, we had the Imaginary Day, with lectures by Pilar Bayer and Joaquim Agulló, and a lovely ‘barítona’ concert played by Jordi Campos.




Events

Tere Martínez-Seara's Fest (5-9 July, 2022)

The Dynamical Systems Group of the UPC organizes the conference *Global and local aspects in dynamical systems: From Exponentially small phenomena to Instability* GLADS-22 in honor Professor Tere M-Seara on the occasion of her 60th birthday.

She is a Full Professor at the Department of Mathematics (UPC), leader of the Dynamical Systems group (UPC), and member of **IMTech** and CRM. She has done seminal contributions to relevant problems in the field of Dynamical Systems and, in particular, on Arnold diffusion and exponentially small phenomena.

The conference GLADS-22 will take place from July 5 to July 9 2022 at the Institut d'Estudis Catalans (IEC). The conference was originally scheduled for July 2021, but it was postponed due to the pandemic situation.

The congress will bring together a prominent number of distinguished mathematicians in the Dynamical Systems field!

Scientific Committee

- Marie-Claude Arnaud,
- Amadeu Delshams,
- Vadim Kaloshin,
- Rafael de la Llave,
- Susanna Terracini.

Organizing Committee

- Inma Baldomà,
- Marcel Guàrdia,
- Gemma Huguet,
- Tomás Lázaro,
- Pau Martín,
- Carme Olivé,
- Jordi Villanueva.

Reviews

Books

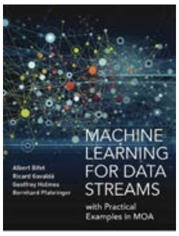
Information geometry and its applications, by Shun-ichi Amari. *Applied Mathematical Sciences*, **194**, Springer, 2016. xiii+374 p.

From the Preface: "Information geometry is a method of exploring the world of information by means of modern geometry. Theories of information have so far been studied mostly by using algebraic, logical, analytical, and probabilistic methods. Since geometry studies mutual relations between elements such as distance and curvature, it should provide the information sciences with powerful tools.

Information geometry has emerged from studies of invariant geometrical structure involved in statistical inference. It defines a Riemannian metric together with dually coupled affine connections in a manifold of probability distributions. These structures play important roles not only in statistical inference but also in wider areas of information sciences, such as machine learning, signal processing, optimization, and even neuroscience, not to mention mathematics and physics. It is intended that the present monograph will give an introduction to information geometry and an overview of wide areas of application."

"Now information geometry has been developed worldwide and many symposia and workshops have been organized around the world. Its areas of application have been enlarged from statistical inference to wider fields of information sciences."

From page p. 313: "Watanabe and his school (Watanabe 2001, 2009) have studied the effects of singularity in Bayesian inference by using modern algebraic geometry. The theory uses deeper knowledge of mathematics and is beyond the scope of the present monograph." The title of the 2009 book by Sumio Watanabe is ***Algebraic Geometry and Statistical Learning Theory*** and was published by Cambridge University Press.



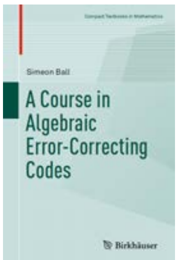
Machine learning for data streams, with practical examples in MOA, by A. Bifet, R. Gavaldà, G. Holmes, and B. Pfahringer. The MIT Press, 2017.

From the Preface: "This book presents many of the algorithms and techniques that are currently used in the field of data stream mining. A software framework that implements many of the techniques explained in this book is available from the Web as the open-source project called MOA [Massive Online Analysis]. The goal of this book is to present the techniques in data stream mining to three specific groups of readers:

1. Readers who want to use stream mining as a tool, who do not have a strong background in algorithmics or programming, but do have a basic background in data mining. An example would be students or professionals in fields such as management, business intelligence, or marketing. We provide a hands-on introduction to MOA, in a task-oriented (not algorithm-oriented) way.

2. Readers who want to do research or innovation in data stream mining. They would like to know details of the algorithms, evaluation methods, and so on, in order to create new algorithms or use existing ones, evaluate their performance, and possibly include them in their applications. This group comprises advanced undergraduate, master's, and PhD students in computing or data science, as well as developers in innovative environments.

3. Readers who, in addition to the above, want to try including new algorithms in MOA, possibly contributing them to the project. They need to know the class structure of MOA and how to create, for instance, new learners for MOA." (from the Preface).

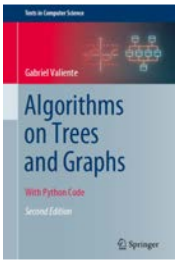


A course in algebraic error-correcting codes, by Simeon Ball. *Compact Textbooks in Mathematics*, Birkhäuser, 2020. xiii+177 p.

Zbl 1454.94142: "This book is a comprehensive introduction of the theory of algebraic coding theory to students at the Master's level. It synthesizes into a well-organized and readable textbook the most important topics in coding theory, and also some of its applications.

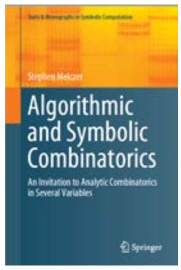
The first chapter of the book is devoted to the presentation of Shannon's theorem, which provides a motivational reason for the study of error-correcting codes. Chapter 2 introduces finite fields, polynomials over such fields, and geometries in positive characteristic. From Chapter 3 to Chapter 6, the book is devoted to developing the classical theory of block codes, introducing their patterns, linear codes, classical bounds, and also relevant families of codes (i.e. Cyclic codes and MDS codes). The remaining part of the book investigates more advanced topics: Chapter 7 deals with Alternant and Algebraic Geometric codes, Chapter 8 investigates LDPC codes, Chapter 9 studies Reed-Muller and Kerdock codes, while Chapter 10 introduces p-adic codes.

The undisputed merit of this book is its ability to bring together many topics, including current research, in a compact volume. Moreover, throughout the book, the author provides exercises that stimulate the interest of the reader. The style is clear and the topics are well presented, which makes the understanding of the subject approachable even for students coming from applied sciences. This is a remarkable textbook for a self-contained introduction to the theory of error-correcting codes and some of their modern topics." Reviewer: Matteo Bonini (Trento).



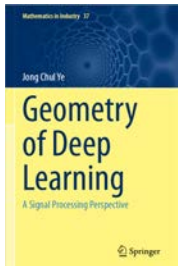
Algorithms on Trees and Graphs **(2nd edition)**, by Gabriel Valiente. **Texts in Computer Science**, Springer 2021, xv+388p.

The first edition of this book was published by Springer in 2002. According to Fabrizio Luccio's assessment in **MR1926815**, "the author of the book is a recognized international expert on tree algorithms". The reviewer also states that the book is "particularly useful for the explicit implementation of all the algorithms discussed". As documented in Appendix C of the second edition, the first edition has been cited by hundreds of publications (books, papers, MSc and PhD theses, and also in sixteen US patents), which show that it has had a remarkable influence on graduate teaching, in research, and in applications. The algorithms in the new edition are described in a remarkably nitid pseudo-code, with enough detail "to allow for a straightforward implementation of the algorithms in any modern programming language". In fact, Appendix A offers "proof-of-concept implementations in Python of all the algorithms". Altogether, the book amounts to a thoroughly revised edition, with several theoretical innovations based on graph transversal techniques, and also with solutions to all the exercises (in Appendix B).



Algorithmic and Symbolic Combinatorics. An Invitation to Analytic Combinatorics in Several Variables

by Stephen Melczer. *Texts & Monographs in Symbolic Computation*, Springer 2021, xviii+418 p. "The book contains deep theorems, yes, but it embodies much more: a tutorial in computer algebra, expertly conceived illustrations, and a very rich collection of examples. Among the examples one finds Kronecker coefficients, rational period integrals, and models from statistical physics. The author's background in lattice walk enumeration keeps the book grounded in yet another source of compelling examples. As the title implies, this book succeeds where our own arguably has not, in making this material inviting. Those taking up the invitation to ACSV will be expertly guided into beautiful new territory" (from the Foreword by Robin Pemantle and Mark Wilson).



Geometry of Deep Learning. A signal processing perspective

by Jong Chul Ye. *Mathematics in Industry*, volume 37, Springer 2022, xvi+330 p.

"The focus of this book is to give students a geometric insight that can help them understand deep learning in a unified framework, and I believe that this is one of the first deep learning books written from such a perspective. As this book is based on the materials that I have prepared for my senior-level undergraduate class, I believe that this book can be used for one-semester-long senior-level undergraduate and graduate-level classes. In addition, my class was a code-shared course for both bioengineering and math students, so that much of the content of the work is interdisciplinary, which tries to appeal to students in both disciplines" (from the Preface). "The field of deep learning is interdisciplinary [...] Therefore, collaborative research efforts between mathematics and other fields are crucial" (from Summary and Outlook).

Papers

The geometric structure of interfaces and free boundaries, by Joaquim Serra. *EMS Magazine* **120**, June 2021 (Online version).

From the abstract: "Interfaces are surfaces that separate two regions of space with different physical properties. The understanding of their geometric structure has boosted the development of Nonlinear Elliptic PDEs during the second half of the 20th century, and continues to do so at the beginning of the 21st." This paper vividly delineates the current state of research in the areas mentioned in the title, with emphasis in the recent fundamental contributions of the author in joint work with coworkers Alessio Figalli, Xavier Cabré, Xavier Ros-Oton, Eleonora Cinti, and Enrico Valdinoci.

The paper is divided in three sections and the references include 43 works. The first section presents background material on minimal surfaces. The second section deals with "Interfaces in phase transitions" and culminates by mentioning a key result published in "On stable solutions for boundary reactions: A De Giorgi-type result in dimension $4+1$", by A. Figalli and J. Serra (*Inventiones Mathematicae* **219** (2020), 153-177), and the role played by ideas related to *nonlocal minimal surfaces* obtained earlier in collaboration with E. Cinti and E. Valdinoci (*Journal of Differencial Geometry* **112** (2019), 447-504). The third section, "The obstacle problem and Stefan's problem", focuses on the main results in three landmark papers: "On the fine structure of the free boundary for the classical obstacle problem", by A. Figalli and J. Serra (*Inventiones Mathematicae* **215** (2019), 311-366); "Generic regularity of free boundaries for the obstacle problem", by A. Figalli, X. Ross-Oton and J. Serra (*Publications Mathématiques de l'Institut des Hautes Études Scientifiques* **132** (2020), 181–292); and "The singular set in Stefan's problem", by the same three authors (Preprint).

Comparing chaotic and random dynamical systems, by Lai-Sang Young. *Journal of Mathematical Physics* **60** (2019), doi.

This article expands the ideas presented at the November 24 **IMTech** Colloquium by Professor Lai-Sang Young about random and chaotic dynamical systems: "This is a slightly expanded version of the plenary lecture the author gave at the International Congress on Mathematical Physics 2018 in Montreal, Canada. Reported are some work of the author and collaborators as well as related results of others on two kinds of dynamical systems: the first kind is deterministic (in the sense that nothing is left to chance) but is chaotic and unpredictable, and the second kind has a stochastic component in addition to a purely deterministic one. These two kinds of dynamical systems are compared and contrasted. The main points are that time series of observations from chaotic deterministic systems obey some of the same probabilistic limit laws as genuinely random stochastic processes, but random dynamical systems enjoy nicer properties and are technically more tractable" (*Abstract*).

A theory of direction selectivity for macaque primary visual cortex, by Logan Chariker, Robert Shapley, Michael Hawken, and Lai-Sang Young. *Proceeding of the National Academy of Sciences* **118** (32), August 2021, doi.

Lai-Sang Young (see the previous review) has also done important contributions in the field of Theoretical Neuroscience. This article presents a novel model that explains how the visual system performs motion detection: "Motion perception is important for primates, and direction selectivity (DS), the ability to perceive the direction a target is moving, is an essential part of motion perception. Yet no satisfactory mechanistic explanation has been proposed for the origin of DS in the primate visual cortex up until now. In this paper, we hypothesize that DS is initiated in feed-forward LGN input as a result of the dynamic differences between the ON and OFF pathways. The mechanisms we propose are biology based, and our theory explains experimental data for all spatial and temporal frequencies in visual stimuli. Exploiting temporal biases in parallel pathways is relevant beyond visual neuroscience; similar ideas likely apply to other types of neural signal processing" (*Abstract*).

On sets defining few ordinary planes
by Simeon Ball. *Discrete Computational Geometry* **60**/1 (2018), 220-253.

From MR3807355: "This is a wonderfully written, thoughtfully crafted paper. Given that the reader is familiar with the Sylvester-Gallai theorem, and the recent related work by Green and Tao on sets defining few ordinary lines, this article is fairly self-contained. The author employs techniques from different areas, from graph theory and counting to some algebraic geometry, and each is given its own space to prevent the ideas from being muddled together. Also, several very clear figures are given that enhance the exposition, which could otherwise potentially become cumbersome and difficult to visualize. The organization of the various pieces of the argument make the distinct ideas from the structure theorems easy to digest and potentially adapt for other purposes. There is also a concise proof of the "eight associated points theorem" in the appendix" (Reviewed by Steven Senger).

On sets of points with few odd secants
by Simeon Ball and Bence Csajbók. *Combinatorics, Probability and Computing* **29**/1 (2020), 31-43.

From MR4052926: "In this paper, the authors show the following beautiful theorem: Let S be a set of $q+2$ points in $PG(2,q)$, q odd. Then the number of lines meeting S in an odd number of points is at least $2q-c$ for some constant c. A conjecture from [P. N. Balister et al., J. Combin. Des. 22 (2014), no. 10, 435–451; MR3247028] says that the correct constant would be $c=2$. The main idea of the proof is to study the subset T of points of S lying on one tangent, one 3-secant, and $q-1$ bisecants. The authors manage to show that all but a constant number of the points of T lie on a conic, which eventually also leads to a proof of the main theorem. In the proof, they use a coordinate-free version of a 'Segre-type' argument, which has been used successfully before by the first author when dealing with arcs [S. Ball, J. Eur. Math. Soc. (JEMS) 14 (2012), no. 3, 733–748; MR2911882; S. Ball and M. Lavrauw, J. Combin. Theory Ser. A 160 (2018), 261–287; MR3846204]" (Reviewed by Geertrui Van de Voorde).

Noether Networks, meta-learning useful conserved quantities
by Ferran Alet, Dylan Dobler, Allan Zhou, Josh Tannenbaum, Kenji Kawaguchi, Chelsea Finn. *Advances in Neural Information Processing Systems* **34** (2021). pdf.

"Progress in machine learning stems from a combination of data availability, computational resources, and an appropriate encoding of inductive biases. Useful biases often exploit symmetries in the prediction problem [...] Automatically discovering these useful symmetries holds the potential to greatly improve the performance of ML systems, but still remains a challenge. In this work, we focus on sequential prediction problems and take inspiration from Noether's theorem to reduce the problem of finding inductive biases to meta-learning useful conserved quantities. We propose Noether Networks: a new type of architecture where a meta-learned conservation loss is optimized inside the prediction function. We show, theoretically and experimentally, that Noether Networks improve prediction quality, providing a general framework for discovering inductive biases in sequential problems" (from the *Abstract*).

Quotations

David Graeber David Wengrow (2021)

Once upon a time, the story goes, we were hunter-gatherers, living in a prolonged state of childlike innocence, in tiny bands. These bands were egalitarian; they could be for the very reason that they were so small. It was only after the 'Agricultural Revolution', and then still more the rise of cities, that this happy condition came to an end, ushering in 'civilization' and 'the state' – which also meant the appearance of written literature, science and philosophy, but at the same time, almost everything bad in human life: patriarchy, standing armies, mass executions and annoying bureaucrats demanding that we spend much of our lives filling in forms.

(*The dawn of everything. A new history of humanity*, page 16)

Richard Feynman (1955)

Of all its [science's] many values, the greatest must be the freedom to doubt.

("The Value of Science", in *Engineering and Science*, volume **xix**, page 13)

Francis Crick (1995)

I believe that when the neural basis of consciousness is thoroughly understood this knowledge will suggest answers to two major questions: What is the *general* nature of consciousness, so that we can talk sensibly about the nature of consciousness in other animals, and also in man-made machines, such as computers? What advantage does consciousness give an organism, so that we can see why it has evolved?

(*The Astonishing Hypothesis: The Scientific Search for the Soul*, Charles Scribner's Sons, page 252)

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