ECMI Mission

Mathematics, as the universal language of the sciences, plays a decisive role in technology, economics and the life sciences. European industry is increasingly dependent on mathematical expertise in both research and development to maintain its position as a world leader for high technology and to comply with the EU 2020 agenda for smart, sustainable and inclusive growth. ECMI initiatives in response to these needs may be summarized as follows:

- ECMI advocates the use of mathematical modelling, simulation, and optimization in industry
- ECMI stimulates the education of young scientists and engineers to meet the growing demands of industry
- ECMI promotes European collaboration, interaction and exchange within academia and industry

Mathematics with industry: driving innovation

Annual Report 2017
Mathematics with industry: driving innovation

Annual Report 2017

ECMI EUROPEAN CONSORTIUM FOR MATHEMATICS IN INDUSTRY
<table>
<thead>
<tr>
<th>Page</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Editorial</td>
</tr>
<tr>
<td>2</td>
<td>Welcome from the President</td>
</tr>
<tr>
<td>3</td>
<td>Activities and Initiatives</td>
</tr>
<tr>
<td>5</td>
<td>131st ESGI</td>
</tr>
<tr>
<td>4</td>
<td>Featured People</td>
</tr>
<tr>
<td></td>
<td>Interview: Peregrina Quintela</td>
</tr>
<tr>
<td></td>
<td>Interview: Milana Pavić-Čolić</td>
</tr>
<tr>
<td>5</td>
<td>Projects and Case Studies</td>
</tr>
<tr>
<td></td>
<td>Universality</td>
</tr>
<tr>
<td></td>
<td>Optimization of buckling for textiles</td>
</tr>
<tr>
<td></td>
<td>Dynamics of the capillary rise</td>
</tr>
<tr>
<td></td>
<td>Mathematical Algorithms for MICADO</td>
</tr>
<tr>
<td>6</td>
<td>Educational Committee</td>
</tr>
<tr>
<td></td>
<td>Experience as an Instructor during a Modelling week</td>
</tr>
<tr>
<td></td>
<td>University of Verona</td>
</tr>
<tr>
<td>7</td>
<td>ECMI Special Interest Groups (SIGs)</td>
</tr>
<tr>
<td></td>
<td>Math for the Digital Factory</td>
</tr>
<tr>
<td></td>
<td>Sustainable Energies</td>
</tr>
<tr>
<td></td>
<td>Computational Finance</td>
</tr>
<tr>
<td></td>
<td>Mathematics for Big Data</td>
</tr>
<tr>
<td></td>
<td>Liquid Crystals, Elastomers and Biological Applications</td>
</tr>
<tr>
<td></td>
<td>Shape and Size in Medicine, Biotechnology and Materials Science</td>
</tr>
<tr>
<td></td>
<td>Advancing the Design of Medical Stents</td>
</tr>
<tr>
<td></td>
<td>Net Campus for Modeling Education and Industrial Mathematics</td>
</tr>
<tr>
<td>8</td>
<td>About ECMI</td>
</tr>
<tr>
<td>9</td>
<td>Institutional members</td>
</tr>
</tbody>
</table>
Dear Colleagues!

When this issue leaves the printers shortly, many ECMI members will already have their eyes set on this year’s ECMI conference in Budapest. The biannual series effectively started 35 years ago, in 1983, in one of the epicenters of mathematics, Oberwolfach, followed by Amsterdam and then Oberwolfach again for the third conference in 1987. These conferences did not yet contain the name of ECMI and ECMI did not exist as an institution; its first president only took office in 1987. After that, the series acquired its current name. Conference sites moved around Europe, to the North, South and West - but not yet to the East: This year’s 20th European conference on Mathematics is the first one to be in an East European city!

This comes at a time when Industrial Mathematics (or Maths in Industry) is gaining a stronger foothold in the Eastern European countries – only this year, Romania joined the ranks of ECMI. Hence the idea that it is worthwhile for mathematics to engage with industry - and vice versa! - continues to spread since 1983, when the concept of a study group and "Maths in Industry" as a discipline were new and needed to be explained to the many uninitiated. Today, the addition of new members and the ongoing Modelling Weeks and European Study Groups demonstrates that ECMI and its view on mathematics and the interaction with industry are alive and thriving. It still continues to bring together Mathematicians and practitioners of the various branches of industry – do take a look at the 2017 report, or come to Budapest, if you need any reassurance.

See you all in Budapest!

Andreas Münch, University of Oxford, May 2018
Welcome from the President

Dear colleagues,

This is already my second and last welcome letter as president before Adérito Araújo takes over and I would like to thank him and the other board members (Poul Hjorth, Jan ter Maten, Stephen o’Brien, Cláudia Nunes, Wil Schilders) for their support during the last two years.

Recently, a number of activities in industrial mathematics have been initiated supported by ECMI. EU-MATHS-IN, the European Service Network of Mathematics for Industry and Innovation is a top-down network of networks striving to emphasise the importance of mathematics for innovations in key technologies on a European scale. The COST action TD1409, Maths for Industry Network, aims at increasing the interaction between industry and academia by running industry workshops, training weeks, and short-term scientific missions to both academic and industrial hosts.

But besides all these important activities, ECMI remains a cornerstone for the collaboration between academia and industry in Europe. As a bottom-up network of more than 100 institutional members in 24 European countries and Israel, ECMI's Educational Committee today oversees more than 20 high-standard master programmes in industrial and econo-mathematics, it organises modeling weeks and summer schools. We support the European collaboration, interaction and exchange within academia and industry in Special Interest Groups. Moreover, ECMI now oversees the European Study Groups with Industry, a by now 50 years old success story in fostering math and industry collaboration. The third pillar of ECMI’s work is outreach: we have a Springer bookseries and a journal in Industrial Mathematics. As a service to the community, ECMI has established a new blog providing up-to-date information on workshops, projects, positions and opportunities in industrial and applied mathematics. Last but not least the outreach events with highest visibility are the biennial European Conferences on Mathematics for Industry. This summer we will have the
20th ECMI conference in Budapest. All in all it is fair to say that ECMI is a truly European success story proving the benefit of international collaboration and I am very grateful that I had the chance to contribute to its development as president during the last two years.

Now, presidents come and go every other year but before I come to an end it is my pleasure to express my great appreciation to Jan ter Maten for eight years of dedicated and invaluable service to ECMI. Since 2008, Jan served ECMI in dual role both as treasurer and secretary. He has been a pillar of trust and a steadfast guardian of ECMI’s funds, he was the primary contact for all ECMI members and supported four presidents in preparing and holding numerous council and board meetings!

From 2018, the duties as secretary will be taken over by our executive director, Poul Hjorth. Moreover, I'm happy to announce that Thomas Götz from the University of Koblenz-Landau has accepted to be the treasurer for the next four years. Together with our new president Adérito Araújo and our new vice president Nataša Krejič I am sure they will do an excellent job in shaping ECMI’s future in the coming years.

Dietmar Hömberg
Weierstraß-Institut and Technische Universität Berlin
May 2018
Activities and Initiatives
The 131st European Study Group with Industry took place in Bilbao, Spain, from 15th to 19th May 2017 at BCAM - the Basque Center for Applied Mathematics. This was the first time an ESGI was held in the Basque Country.

BCAM (www.bcamath.org) is the research center on Applied Mathematics which aims to strengthen the Basque science and technology system, by performing interdisciplinary research in the frontiers of mathematics, excellence scientific research, talented scientists’ training, and attraction.

During an exciting week, companies and academic participants with expertise in Mathematical fields joined their efforts to create new mathematical solutions for the needs of the Basque industry.

“Mathematics, a world of possibilities at the service of Basque industry”

Challenges

At the 131st ESGI, the participants worked on four challenges:

1. Parametric Design by Computational Fluid Dynamics Simulation.
2. Improvement of the Contact Center Performance.

The 4th Challenge was of particular interest for many participants and a success story which encompasses data analysis and a variety of mathematical techniques from statistical learning, regression techniques...
and predictive modelling of Basketball player’s performance from a historical database of professional Basketball leagues.

Data Science in professional Basketball

Data analytics in professional sports has experienced such rapid growth in recent years that the way professional sports are managed is changing. The world of professional sports is only just starting to explore this world of applying Data Science to gain a competitive advantage.

“The world of professional sports is only just starting to explore this world of applying Data Science to gain a competitive advantage”

**Aryuna** is a platform that allows performing advanced data analytics of men’s professional basketball statistics of the last 16 seasons in more than 25 professional leagues and 71 FIBA tournaments. The challenge consisted of the next four goals:

1. Study the performance curve, peak and optimal age of a basketball player in top European leagues.
2. Player’s performance and their influence in the game.
3. Rating correction factor for different basketball leagues.
4. Which factors predict a successful professional career?

**Sports metrics**

*Sports metrics* is the term for the empirical analysis of Statistics in sports that measure in-game productivity and efficiency. In basketball, player’s statistics are usually produced by the player per 100 Team’s possessions. Some important metrics are:

- **OE (Offensive Efficiency)**: measures the quality of offensive production. OE is the total number of successful offensive possessions the player was directly involved in divided by that player’s total number of potential ends of possessions.

- **EOP(Efficient Offensive Production)**: is defined as

  $$EOP = (0.76 \times \text{Assists} + \text{Points}) \times OE$$

**Data and Methods**

A database containing a total of 44 variables of 5227 professional basketball players during seasons 2000-2015, and six competitions (Euroliga, Eurocup, ACB, Argentina, ABA, ProA) was provided for the challenge. The participants of this challenge worked in small groups and used the Open Source Software R to perform the Statistical analysis and fit statistical models.

In order to address the 1st goal and study the performance curves, the *EOPx40M* (EOP per 40 minutes) for each player in all seasons and competitions was considered in a linear mixed-effects model with variables “Position” (center, forward and guard) and “Age”, a quadratic term for “Age” and interaction terms between “Position” and “Age”. The variability of the player’s was accounted by a random effect term, i.e. $$u_{player} \sim \mathcal{N}(0, \sigma^2_{player})$$. The quadratic term of the model is intrinsically assuming that professional athletes performance is unimodal (i.e., it reaches a maximum). The model was fitted with the function *lme* from the R library for linear mixed-effects models *nlme*. 
Figure 2, shows the fitted curves, where the peak of performance for “Ages” (and their 95% confidence intervals) by “Position” are 
Center: 27.23 (26.48, 27.98) years; Forward: 27.46 (27.00, 27.92) years and Guard: 28.08 (27.57, 28.59) years. These peaks and their statistical uncertainties are between 26 and 29, which are similar to those for the NBA, 27-30.

![Figure 2: Performance curves by “Age” for centers, forwards and guards. Their respective maxima are represented by dots.](image)

However, one might be interested in the peak performance of a player’s EOPx40M based on his experience as a professional basketball player. Therefore, the same linear mixed-effects model was fitted, including a new variable we named as “Years of experience” instead of “Age”. This new variable was created assuming that those players from the 2001 season younger than 20 were playing their first season. This new variable may account for the fact that the peak performance reaches a different maximum depending on the player’s position. Peak performance for “Experience” (and their 95% confidence intervals) by position are Center: 10.63 (2.37, 18.88) years; Forward: 7.35 (5.76, 8.93) years and Guard: 9.46 (6.38, 12.55) years.

![Figure 3: Performance curves by “years of experience” for centers, forwards and guards. Their respective maxima are represented by dots.](image)

For the 2nd goal (“Player’s performance and their influence in the game”) we started considering the player’s shot precision (i.e.: Free-throws, 2-Points and 3-Points shoots). Thus, we consider the performance by “100xPosseions” or “x40 Minutes”. The results for this goal were not conclusive to confirm any evidence of player’s performance in the game. We consider the player’s performance based on the teammates on the court might be important information to be considered in further analysis.

For the 3rd goal (“Rating correction factor for different basketball leagues”). We consider basketball competitions may be different depending on the level of the teams/players, the number of games, the level of competitiveness, offensive or defensive game-play, etc. The Euroleague is the most prestigious basketball competition around the world besides NBA, and it is played by top teams in Europe. During the regular season, the teams in the Euroleague also compete in their local competition.
Argentina league was also considered for the analysis because many players of that league end up playing in Europe and vice versa. All those aspects were modelled using Analysis-Of-Variance (ANOVA) models for some particular variables such as “Points” (scored/attempted), “Fouls”, “Blocks”, “Offensive” and “Defensive rebounds”, “Steals”, “Turnovers” or “Assists” per 100 possessions.

Table 1. Summary of ANOVA models for each of the basic game variables. Darker colors imply smaller p-values ranking from <0.001 to <0.01, to <0.05 and to <0.1.

Table 1 present some evidence about the difference among the leagues.

Finally, the 4th goal (“Which factors predicts a successful professional career?”) was the most challenging task. As a measure of success, we considered the variable $EOPx40M$ converted to a binary variable (0=Fail and 1=Success), where above the 10th quantile of $EOPx40M$ among all players is equal to 1, otherwise 0.

The odds-ratios (OR) of the most highly correlated variables (9 out of 13) predicted with the random forest algorithm are shown in Figure 5. A OR's greater than 1, indicate the variables more likely the event of success. Variables such as “Steals” and “OffensiveRebounds” (not included in the EOP formula) have an estimated OR close to 2.

Conclusions

The data analysis of this challenge provided statistical evidence from a large historical professional basketball sport metrics. The ESGI team provided new insights that may help to provide new perspectives to basketball management and sports data analytics via statistical modelling. The group made lots of interesting suggestions to the company specialists, particularly on the design of data acquisition tool and codification of some of the variables. There are some open questions suggested by the ESGI team, such as the subjective nature of some metrics (as it is not easy to find a overall global measure), since most of them, favours the offensive game play rather than defensive game play. For the successful career, the interest of the professional basketball managers is to know which variables can help them to identify a
potential top player. i.e., a successful career can be considered as, winning an MVP (most valuable player) trophy or signing a long-term contract with an NBA team. Unfortunately, the database did not contain such information in order to measure success.

Summary of the 131st ESGI

For the Basque Center for Applied Mathematics, the ESGI was a great opportunity to attract companies and more than 30 academic participants including Master and PhD students, Postdoctoral fellows with expertise in Mathematical fields including Computer Science, Statistics and Engineering to create new mathematical solutions for the Basque industry. 

Laster arte ESGI ! (see you soon ESGI !).

Visit the event webpage at https://wp.bcamath.org/esgi131

Ainara González
Dae-Jin Lee

Basque Center for Applied Mathematics
Featured People
Today we are interviewing Professor Peregrina Quintela from the Universidade de Santiago de Compostela, known mainly for her incessant activity in the promotion of Industrial Mathematics. She was President of the 2016 ECMI Conference Organizing Committee, which was held in Santiago de Compostela in June 2016, and a leading figure in the creation and support of national networks of Industrial Mathematics.

You have been a promoter and first president of the Spanish Network for Mathematics & Industry in 2011. What led you to promote this initiative?
Actually the creation of the “math-in” network was something natural: in Spain there are numerous research groups with a special inclination to developing new technologies applicable to the industry. At some point, with all the accumulated experience, it was clear that an effort had to be made to make companies aware of the great potential of Mathematics, something that many of them did not know. This became a challenge for all of us, Spanish mathematicians. We were looking for a way to show with practical cases and simple language the ability of Mathematics to provide solutions adapted to each industry demand. We needed to establish a structure that was broad and coordinated so we could quickly connect a company with the most experienced researcher in their area. And obviously, being such a heterogeneous group of researchers scattered throughout Spain does not help. It was necessary to establish synergies among us, quickly connect supply and demand and, above all, to sensitize companies to generate new demands. That is how the “math-in” network was launched, completely fitted to respond to these needs.

What strategies have been followed to achieve these objectives that you have highlighted?
We cannot talk about a single strategy, but a combination of several. In the first place, a climate of trust among the mathematicians themselves was generated; this allowed us defining a single catalogue of mathematical technologies for the industry in Spain. At the same time, we carried out a macro survey to establish a demand map for mathematical technology that would allow us to better understand our industry and its needs. Both studies were combined with multiple informative efforts, such as visiting
representative enterprises, organization of dissemination days and workshops, participation in technology platforms and forums in which the majority of attendants are from the industry.

How many research groups and researchers participate in math-in? Nowadays, about thirty research groups of almost 20 Spanish universities and research centers are membership of “math-in”; this means more than 450 Spanish researchers. We also have sponsor companies such as Arcelor Mittal, BSH Electrodomésticos, or Repsol.

How is the involvement of the Spanish network in EU-MATHS-IN? You are also part of the Board Committee, right? Actually, “math-in” was one of the six founding networks of EU-MATHS-IN. We started this initiative in 2013 seeking to intensify collaboration with industry at a European level. To achieve this, EU-MATHS-IN tries to connect the national networks of the different countries—currently there are already 17—and harmonize a joint path. In this sense, a lot of work has been done using several complementary strategies too. We have pushed to place Modelling, Simulation and Optimization (MSO) as an emergent technology in the European institutions, and in particular in the strategic lines of the H2020 Programme. We started an initiative to implement a European technological platform for which a good number of big European companies have been mobilized, all of them convinced of the essential role that Mathematics must play in their processes improvement. I am convinced that achievements in this area will soon be seen. Attention has also been given to industrial doctorates, which allow for effective collaborations between Academia and Industry in the training of young researchers. This new worker profile is of great interest for the industry and will be our best ambassadors in the future. Just recently, two H2020 proposals have also been submitted, targeting industry and innovation through MSO. So since at “math-in” we are convinced that international cooperation can be a determining factor in the future of Industrial Mathematics and the society in general, “math-in” itself is collaborating, supporting, and promoting joint initiatives with EU-MATHS-IN.

In addition, you are the director of the Technological Institute of Industrial Mathematics (ITMATI) that was created in 2013. Why did the need arise to create this Institute? ITMATI was the result of an agreement between the three Galician universities to unite around 150 researchers with a strong vocation towards the effective transfer of knowledge developed in their universities. We are talking about a region in north-western Spain that constitutes a microcosm with a history of more than thirty years effectively collaborating with the industry. ITMATI was launched in 2013 as a new concept of the Technology Transfer Unit, since it not only promotes and facilitates the transfer but also executes its own projects and transfer contracts. Senior researchers who pass a selective process can dedicate up to 25% of their day to the institute, and this is our greatest asset.

How do you think the transfer activity developed in ITMATI enrich the microcosm to which you referred? There is no doubt that it has professionalized the transfer activity towards companies, and it provides more agile responses. ITMATI has also created an Academia-Industry bridge for the training of recent graduates, both for the completion of Master’s thesis and industrial doctorates. So I think that it is indirectly improving the social projection of mathematicians and their professional outings towards
non-academic works, since many of our contracted are being successfully inserted in the industry. Also the research groups are enriched with our activity since they maintain a continuous renewal of their lines of research orienting them more towards the real demand. So this microcosm continues to grow with ITMATI activities.

How is financing found for this kind of initiatives? Are they well supported by universities or other public institutions? Actually, these are initiatives that are the result of the illusion and unselfish contribution of many researchers. In this sense I believe that we mathematicians can organize ourselves with no strong self-interests, making it easier to drive efforts towards a common good and a better future for all. However, many institutions just do not believe it and still do not bet on initiatives like “math-in” or ITMATI. For example, math-in does not have direct public funding; it only has financing from its partners’ fees, or indirectly through the contracts it promotes. In ITMATI the financing is being obtained mainly thanks to the private sphere, which for example in 2017 has meant a turnover of 90% of its budget. Of course, I would tell the institutions responsible for Science to bet on these modern intermediate infrastructures that agglutinate the interests of a large group and with great potential for advancement and smart digitization of the industry.

You belong to the Mathematical Engineering research group of the Universidade of Santiago de Compostela. What does your group fundamentally work on?

Our group, led by Professor Alfredo Bermúdez, focuses on modelling, mathematical analysis, and the numerical simulation of industrial problems. It is a group with very varied fields of interest, ranging from Solid Mechanics to Fluids, Heat Transfer, Acoustics, Chemical Kinetics, Combustion, or Electromagnetism, and the multiple coupling of several of these phenomena. This has allowed contributions to the industry in very different fields and sectors. The list would be very long, so just to name a few, I would like to mention the thermoelectric simulation of aluminium electrolysis cells, the adaptation and optimization of vacuum furnaces for the evaporation of impurities, the modelling and optimization of gas transport networks, the development of efficient silicon production strategies, the prediction of the quality of water in the recovery of coal extraction mines as lakes, or the acoustic insulation of buses and cars. Our research group has maintained stable objectives since the year of its creation in 1986, always with a focus on applied and industrial research, and that is what has also motivated me to accept responsibilities aimed at consolidating this Mathematics and Industry tandem.

Finally, what actions do you think should be addressed to further enhance the presence of Mathematics in the industry?

I believe that Mathematics are the DNA of Industry, they are everywhere, but many times, as you cannot see them, you are not aware of it. Therefore, to continue moving forward, I believe that a lot of fieldwork is necessary. We need to relate more to companies, become more reliable and competent partners for them, and to erase the idea from the collective subconscious that university researchers are dilators, who do not come down to reality. On the other hand, it is also necessary to end the idea that many mathematicians have that industrial mathematics are interesting but not very prestigious.

Interviewed by Elena Vázquez Cendón

Universidade de Santiago de Compostela, Spain
Tell us about yourself: what is your background and training?
My name is Milana Pavić-Čolić. Currently, I am assistant professor at Department of Mathematics and Informatics (DMI), Faculty of Sciences, at the University of Novi Sad in Serbia.

At bachelor and master level, I was student of Applied Mathematics at DMI. Shortly after my graduation I became a PhD student in cotutelle between the University of Novi Sad and the École Normale Supérieure de Cachan in France, as a French Government fellow. I worked with prof. Srboljub Simić and prof. Laurent Desvillettes, mainly focusing on comparisons of mathematical models for polyatomic gases and mixtures in the context of kinetic theory of gases and fluid mechanics.

What is your research area?
My research interests focus in the area of collisional kinetic theory of gases that models a wide range of physical phenomena, from rarefied gas flow mixtures in the upper atmosphere, plasma dynamics to charged hot electron transport in semiconductor devices or the formation of Bose-Einstein condensation. This field belongs to non-equilibrium statistical physics, where models of continuum mechanics fail to accurately describe time dynamics or quantum or molecular systems are not suitable due to the size of the system. I would stress that this area enriches many fields of mathematical research closely connected to physics where probability theory and functional analysis provide the natural framework.

The area of kinetic transport theory is relatively young. Its basic concepts were introduced by Boltzmann at the end of XIX century, marking the birth of statistical mechanics, where flows can be described probabilistically. Mathematicians intertwined their fingers from late ’80 very successfully, culminating with two Fields medals associated to the area, for Pierre Louis Lions in 1994 and Cédric Villani in 2010. Nowadays, we have quite good understanding in the case of monatomic gases, where the model is well described by a single equation that can be viewed as bi-linear Integro-Differential equation. Beyond this setting, where systems of such equations arise, very little is known. And here lays my interests: the enlarging of concepts to tackle the problem for solving mixtures of monatomic and polyatomic gases. This field of research is of fundamental importance to industrial applications from a broad engineering and
science viewpoint, enhances the understanding of a quite broader area of statistical mechanics. It has, indeed, a promising future!

**What are you doing now?**

At this moment, I am visitor at the Institute of Computational Engineering and Sciences (ICES) at The University of Texas at Austin, USA, as a Fulbright Visiting Scholar and JTO fellow at ICES. I am currently working with Prof. Irene M. Gamba on the mathematically rigorous theory for the Boltzmann system in the context of mixture of monatomic gases. For instance, we are dealing with existence and uniqueness theory, propagation and generation of exponential tails. I am looking forward for important results for the theory that also include a detailed description to time decay rate to statistical equilibrium, a quantity that usually can be compared to experimental data. Our work also apply to the development of new computational methods for gas mixtures.

**Your ECMI engagement started when you were a master student. Could you comment from the perspective of a student and an instructor at Modeling Weeks?**

At Modeling Weeks in Milano 2010, for the first time I met real a life problem where I took part in solving it, together with other colleagues from my group. I truly think that Modeling Weeks takes best out of you: the need to apply all your available knowledge to a particular problem within given time framework, jointly with your team members. This was a valuable experience and a wonderful opportunity to meet possible future collaborators!

Later, being an instructor at ECMI Modeling Weeks in Sofia 2016, was very challenging as well, from adapting the problem to its study, to final conclusions with students. I think that, from instructor point of view, Modeling Weeks offers an extraordinary framework for mathematicians to concentrate on a particular problem and hear another opinions (always very constructive!) from student teams.

At final presentations, one can notice the lively and cheerful mood of, both students and instructors, arising as a positive sign of good communication and work.

**How do you see a role of industrial mathematicians in the near future?**

I think that industrial mathematicians play an important role in nowadays society. Applied mathematics has become recognized as a necessary tool in research in all sciences. It is essential to pursue in this direction. When I was preparing problem on *Deer population* for Modelling Week, I initiated meeting with our local National Park Fruška gora. They kindly supported all data that I needed, and appeared to be very surprised by the power of mathematics. Although they provide control on deer population, it is not based on any reliable mathematical model. Therefore, mathematics can help and we should say it loudly.

**What are the challenges and opportunities for industrial mathematics in Serbia and South-East Europe as a region? How do you see the role of your Department?**

I believe that the recent inclusion of our DMI as an ECMI Node is one of the most recent important events for industrial mathematics in Serbia. In such a way, DMI has became the Serbian center of Applied Mathematics, giving great opportunities for Serbian industrial mathematics to become more visible, as current applied mathematics strength can be shown mainly through mutual collaborations and synergy between industry and academia. In this context, ECMI Modeling Weeks is definitely a good starting point.

In addition, a current challenging issue all over the world is the inclusion of women in science. I would like to point out that, as a
woman, I am proud that my Department promotes and encourages women to be part of mathematical community. And, as a matter of fact, women are very well represented at our Department.

By promoting these values, I am convinced that Serbia, and DMI, will be able to provide a role model that our neighbors may be willing to embrace.

Interviewed by Prof. Nataša Krejić

University of Novi Sad, Serbia
Projects and Case Studies
Universality from microscopic stochastic dynamics

Many different physical systems, when analysed from a mathematical point of view, show identical patterns of growth. This slightly mysterious tendency for very different things to behave in very similar ways is the essence of universality. Here we report a methodology that connects the macroscopic world with the microscopic behavior of particles and allows to derive rigorously macroscopic universal laws from the random motion of the underlying microscopic dynamics.

In real life situations we come across with many different episodes where we feel that it has similarities with something we have lived before in the past. Either this is related to emotions or to physical reactions, the similarity can be present. In nature, similarities between very different organisms also occur. As an example of this puzzling reality which somehow connects all of us, in the picture below, we see a growing pattern of ice particles which is formed in a windscreen in a very rigorous winter day.

The ice particles fall, randomly, from the sky and when they hit the windscreen they form a growing pattern which can be seen in other, in principle, uncorrelated, situations as: coffee ring effects, bacterial growth like E-coli, the wake of a flame, tumor growth...

There are various different physical systems, that when they are mathematically modelled they show identical patterns of growth. This slightly mysterious tendency for very different things to behave in very similar ways is the essence of universality. There are different shapes for these patterns and their study is the core of this project and it is related to a very active area of research in both mathematics and physics known as universality. A way to model mathematically the falling of ice particles is to identify them as blocks that fall independently from each other and according to some random law. By this we mean that the time it takes for a block to fall is random and times between the fall of two blocks are independent. Probabilistically speaking we can assume that the law for these times is exponential and moreover,
blocks fall in a sticky way, that is, whenever a falling block touches another block, even only from the side, then it immediately sticks into place. We could have also assumed that blocks fall independently and in parallel above each site according to exponentially distributed waiting times. In this case there is no stickiness. Let us make an analogy with a game that everyone knows: the tetris game. In the latter random deposition, the one without stickiness, the typical pattern we see is like the one on the left hand side in the picture below, this is the usual tetris game; while the typical pattern for the sticky random deposition of particles is like the one on the right hand side in the picture below, which would be a sticky tetris. Obviously a player looses more quickly with the sticky tetris than with the usual tetris game, due to the existence of holes in the pattern.

These two different types of random deposition give rise to two different universality classes. Mathematically speaking, this is a way to catalogue systems that somehow exhibit the same behavior. Above we have seen two universality classes: the random straight deposition is in, what is called, the Gaussian universality class and the sticky deposition is in, what is called, the KPZ universality class. In 1986, three physicists: Kardar, Parisi and Zhang proposed [1] a phenomenological model for the evolution of a random growing interface given by what is called today the Kardar, Parisi and Zhang (KPZ) equation. One of the popular topics in research related to the classification of systems in universality classes, is to explore the universality of this macroscopic law, the KPZ equation, from underlying microscopic stochastic dynamics. Here are some of the questions that people look for answers: What are the macroscopic laws governing the evolution of the conserved quantities of a microscopic stochastic dynamics? What are the universality classes to which the models, with certain general features, belong to? What is the relation between these classes? Are they linked by some parameter prescribed on the underlying microscopic stochastic dynamics? How local dynamical perturbations are “felt” at the macroscopic level?

Here we report a methodology [2] which allows to rigorously prove, the emergence of macroscopic laws from microscopic stochastic dynamics. The goal is to obtain partial differential equations (PDEs) or stochastic PDEs from microscopic systems of random particles, depending on whether one is looking at the law of large numbers or the central limit theorem for those microscopic systems. There are several macroscopic laws which are obtained from many different systems. The goal is to describe these laws by using some underlying models which are analysed from a probabilistic point of view.

This work is being developed in the Mathematics Department of Instituto Superior Técnico (IST) of the University of Lisbon, in the framework of the research project HyLEF: Hydrodynamic Limits and Equilibrium Fluctuations funded by the European research council through an ERC Starting Grant leaded by Patrícia Gonçalves. This project gathers a group of external collaborators from IMPA (Brazil), University Paris Dauphine (France), University of Nice (France), INRIA (France), HU Berlin (Germany) and other institutions abroad. It counts with a local team of post docs and PhD students. For more information check the website: http://patriciamath.wixsite.com/patricia/hylef.
Scientific background

Interacting particle systems, is a recent branch of study in probability theory as part of a general theory known as Markov processes. Interacting particle systems [3] were introduced in the mathematics community by Frank Spitzer in [4], but were already known to physicists, as microscopic stochastic systems, whose dynamics conserves a certain number of thermodynamical quantities of interest.

A classical problem in the field of interacting particle systems is to derive the macroscopic laws of the thermodynamical quantities of a physical system by considering an underlying microscopic dynamics which is composed of particles that move according to some prescribed stochastic, or deterministic, law. The macroscopic laws can be PDEs or stochastic PDEs depending on whether one is looking at the convergence to the mean or to the fluctuations around that mean. The main goals of this research field are related to the mathematical rigorous derivation of these macroscopic laws.

The physical motivation for the study of interacting particle systems is the following. Suppose that we are interested in analysing the evolution of some physical system as, for example, a fluid or a gas. Due to the large number of molecules, it becomes quite hard to analyse the microscopic evolution of the system, so it is more relevant to analyse the macroscopic evolution of its structure.

According to Ludwig Eduard Boltzmann (1844-1906) who was an Austrian physicist and philosopher; and whose greatest achievement was in the development of statistical mechanics, "Statistical mechanics explains and predicts how the properties of atoms determine the physical properties of matter."

Boltzmann proposed an approach which consists in finding first the equilibrium states of that system and then characterizing them through macroscopic quantities, namely, the thermodynamical quantities, such as: pressure, temperature, density, energy... The natural question that arises then is to analyse the macroscopic behaviour of that system out of equilibrium.

"Statistical mechanics explains and predicts how the properties of atoms determine the physical properties of matter."

The characterization and study of phenomena out of equilibrium is one of the biggest challenges of Statistical Physics and despite its long history, a satisfactory answer to this kind of problems has not yet been found, see [5].

From this approach, some PDEs arise that provide information about the macroscopic evolution of the thermodynamical quantities of the system. Due to the huge complexity of the analysis of these systems,
some simplifications need to be introduced. For this purpose, we assume that the underlying microscopic dynamics, that is the dynamics between the molecules, is stochastic. As a consequence, a probabilistic analysis of the system can be done. Assuming that particles (or molecules) behave as interacting random walks, subject to some random local restrictions, arise the interacting particle systems [3].

“Aassuming that particles (or molecules) behave as interacting random walks, subject to some random local restrictions, arise the interacting particle systems [3].”

Probabilistically speaking, these systems are continuous time Markov processes, being the time between consecutive jumps given by an exponential law which has the well-known property of memory loss, therefore, the future of the system, conditioned to its past, depends only on its present state.

By considering these microscopic random systems one can, by a space-time scaling limit, deduce (in a rigorous way) the macroscopic laws governing the evolution of these quantities. These laws give the space/time evolution of the thermodynamical quantities of the system and they are composed of one, or a system, of PDEs. In the literature, this procedure is known as Hydrodynamic Limit.

The scaling limit is done by means of a scaling parameter, that we denote by $n$, which allows us to identify relevant unknowns of the macroscopic space with the respective microscopic space. Therefore if the macroscopic space is, for example, the one-dimensional interval $[0, 1]$, one can divide this space into $n$ subintervals of size $1/n$, in such a way that each element $u \in [0, 1]$ such that $u \in \left[\frac{j}{n}, \frac{j+1}{n}\right)$, is identified with $j$, namely with the closest integer number less or equal to $u$, so that the microscopic space (a discrete space where the random dynamics is defined) is the set of points $\{0, 1, \ldots, n-1\}$.

To summarize, on the underlying scenario we are interested in analysing the physical evolution of, for example, a gas evolving in a certain volume $V$. Two scales are considered: the macroscopic one, that describes the global motion of the gas; and a microscopic one, that describes the movement of the molecules, or particles, of the gas. We can think of these two scales in the following way. If we put a gas in a certain volume $V$ and with our eyes, we look at the evolution of the dispersion of the gas, this would be the macroscopic picture, while if we have a loupe to see how the molecules interact with each other, this would be the microscopic scale.

Due to the large number of molecules, we assume that its motion is not deterministic but stochastic, in the sense that, each particle performs a random walk, that is, it moves, after some specified time, to a position of the discretized volume $V$. The discretization of the volume $V$ is done by means of the scaling parameter $n$. Under the assumption of the random movement of the molecules of the gas, a probabilistic analysis of the system can be performed.

Initially, on the volume $V$, we can consider a point $u$ and a neighbourhood around that point, let us call it $V_u$, and since the number of particles is big, we can assume that locally the microscopic model is equilibrium.
The equilibrium is characterized by the thermodynamical quantity of interest that we denote by $r(u)$. Now we can let the system evolve in time, and for a time $t$, we can pick the same point $u$ in $V_u$, and assume again the local equilibrium, which is now depending also on time and we denote it by $r(t, u)$, see the picture below. The important questions to answer are:

How is the space-time evolution of $r(t, u)$? Is it described by some law? Which law is this?

So, the picture behind our interpretation is the following. First, we suppose to have two scales: one for space and another one for time and to have a physical system evolving in a certain volume $V$. The evolution of its particles is random and is Markovian. In the next step, we discretize the volume $V$, according to the scaling parameter $n$, and we divide it into a certain number of cells. In each cell, we put a random number of particles, being this number given as the result of some random experiment. At each cell, particles wait a random time after which one of them decides to jump to some position of the discretized volume $V$ according to a probability transition rate. The random times are assumed to be independent and exponentially distributed so that interacting particle systems fall into the class of Markov processes, for which there is a very developed theory.

The goal in the hydrodynamic limit theory consists in obtaining the macroscopic laws, which, mathematically speaking, are PDEs, that govern the space-time evolution of each conserved quantity of the system. These macroscopic laws are called hydrodynamic equations.

A prototype example: exclusion process in contact with reservoirs

To explain the hydrodynamic limit let us present a concrete example. For that purpose, let us consider now the prototype example of an interacting particle system: the exclusion process denoted by $\eta_t$, with $t$ running in a compact set $[0, T]$, with $T$ fixed. To make the presentation as simple as possible we consider the process evolving on, for example, $\{1, \ldots, n - 1\}$ which we call the bulk.

The dynamics of the simplest example of exclusion process in contact with reservoirs is defined as follows. Each particle in the bulk waits an exponential time of parameter 1 and then it jumps to a site according to a certain probability transition rate. Due to the exclusion rule, the jump is performed if, and only if, the destination site is empty, otherwise nothing happens and particles wait a new random time. The space state of this process is $\{(0,1)\}^{\{1,\ldots,n-1\}}$. Let us denote the jump rate from $x$ to $y$ by $p(x,y)$.

Here we assume that $p(x,y) = p(y - x)$, that is, the jump rate from $x$ to $y$, depends only on the distance between $x$ and $y$ and we also assume that jumps are allowed only to nearest neighbours. In last case, the process is said to be simple, so that $p(z) = 0$ if $|z| > 1$. In this situation two cases can occur, either the process is symmetric or asymmetric, so that

$$p(1) = p(-1) = \frac{1}{2},$$

or

$$p(1) = 1 - p(-1) = \frac{1}{2} + \frac{a}{n^2},$$

In the former case the process is the symmetric simple exclusion process (SSEP), while in the latter for $a \neq 0$ and $\gamma > 0$, the process is the weakly asymmetric simple exclusion process ($\gamma$-WASEP). Note that the parameter $\gamma$ rules the strength of the asymmetry: the higher the value of $\gamma$ the weaker is the asymmetry.
Now we explain the boundary mechanism. At boundary points $x = 1$ and $x = n - 1$, particles can either be created or annihilated according to the following rates:

- at site $x = 1$:
  - creation rate $\alpha n^{-\theta}$,
  - annihilation rate $(1 - \alpha) n^{-\theta}$,
- at site $x = n - 1$:
  - creation rate $\beta n^{-\theta}$,
  - annihilation rate $(1 - \beta) n^{-\theta}$.

Above the parameters are such that $\alpha, \beta \in (0, 1)$, $\theta \in \mathbb{R}$ and $\kappa > 0$. Note that in any case, the exclusion rule has to be respected. At most one particle is allowed at each site of the bulk so that particles can only be created (resp. removed) at the sites $x = 1$ or $x = n - 1$ if the corresponding site is empty (resp. occupied), otherwise nothing happens.

In the figure below we represent a possible configuration with the description of the dynamics.

![Configuration of the dynamics](image)

If reservoirs are not present, the exclusion dynamics just defined does not destroy the number of particles, since particles move in a discrete space according to some prescribed rule and they are not created nor annihilated, therefore, the density of particles is a conserved quantity of the system.

Since we added reservoirs, the density is no longer conserved and it will be constrained to boundary conditions which depend on the value $\theta$ that rules the strength of the reservoirs.

### Hydrodynamic limits:

Now, we explain in which sense we derive macroscopic laws, that is PDEs, from the previous microscopic stochastic dynamics. Taking into account that the density of particles, is the thermodynamical quantity of interest in the exclusion process, we define a density empirical process. It consists on a process of random measures, such that, for a fixed time $t$, each measure is a sum of Dirac measures supported at each site of $\{1, \ldots, n - 1\}$ that gives weight $\frac{1}{n-1}$ to each particle, namely:

$$\pi_t^\theta(\eta, du) = \frac{1}{n-1} \sum_{x=1}^{n-1} \eta_{\theta(n)}(x) \delta_{\eta_x}(du).$$

Above $\delta_{\eta_x}(du)$ is the Dirac measure of the set $\eta_x$. Note that above since a re-scaling in space is done, we also need to speed up the process in a time scale that we denote by $t \theta(n)$ and which will depend on the choice of the transition probability $p(\cdot)$. The goal in the hydrodynamic limit consists in showing that:

1. if starting the process $\{\eta_{\theta(n)}\}$, from a collection of measures $\mu_n$ for which the Law of Large Numbers holds: the sequence of random measures $\pi_t^\theta(\eta, du)$ converges, in probability with respect to $\mu_n$ and when $n$ is taken to infinity, to the deterministic measure $\rho_0(du)$, where $\rho_0(du)$ is a function defined in $[0, 1]$ which is measurable;

2. then, the same holds at later times $t$, that is, the random measure $\pi_t^\theta(\eta, du)$ converges, in probability with respect to $\mu_n(t)$, the distribution of $\eta_{\theta(n)}$ and when $n$ is taken to infinity, to the deterministic measure $\rho(u)du$, where $\rho(u)$ is the solution (usually in the weak sense) of a PDE, namely, the hydrodynamic equation of the system.

Note that assumption 1. above can be translated by saying that for any continuous function $g : [0, 1] \to \mathbb{R}$ it holds that

$$\lim_{n} \mu_n \left( \left| \int g(u) \pi_t^\theta(\eta, du) - \int_0^1 g(u) \rho_0(u) du \right| > \delta \right) = 0.$$
For exclusion processes defined above, by a scaling limit procedure, one can get as hydrodynamic equations:

1. for the SSEP and re-scaling time diffusively $t \theta(n) = n^2$, the heat equation given by
   \[ \partial_t \rho_t(u) = \frac{1}{2} \Delta \rho_t(u), \quad \text{[Heat equation]} \]
   starting from $\rho_0(u)$ and with the following boundary conditions [6, 7].
   - For $\theta < 1$, Dirichlet boundary conditions:
     - $\rho_t(0) = \alpha$, $\rho_t(1) = \beta$.
   - For $\theta = 1$, linear Robin boundary conditions:
     - $\partial_\rho \rho_t(0) = \frac{\alpha}{2} (\rho_t(0) - \alpha)$,
     - $\partial_\rho \rho_t(1) = \frac{\beta}{2} (\beta - \rho_t(1))$.
   - For $\theta > 1$, Neumann boundary conditions:
     - $\partial_\rho \rho_t(0) = 0 = \partial_\rho \rho_t(1)$.

2. for $\theta = 0$ and for the 1-WASEP and by re-scaling time diffusively $t \theta(n) = n^2$, the viscous Burgers equation, namely,
   \[ \partial_t \rho_t(u) = \frac{1}{2} \Delta \rho_t(u) + (1 - 2\alpha) \nabla f(\rho_t(u)) \]
   with Dirichlet boundary conditions.

Above $f(\rho) = \rho(1 - \rho)$, $\Delta$ is the laplacian and $\nabla$ is the spatial derivative.

“The hydrodynamic limit is then a Law of Large Numbers for the empirical measure.”

We also note that we can get to fractional PDEs from exclusion processes [8, 9]. For example, if we allow the dynamics to have long jumps but still given by a symmetric transition probability $p(\cdot)$ with the rates given by $p(x) = \frac{c_r}{x^{\gamma}}$, where $c_r$ is a normalizing constant and $\gamma \in (1, 2)$, see the figure below:

By re-scaling time as $t \theta(n) = n^\gamma$ we can get in the hydrodynamic limit, the fractional reaction-diffusion equation given by

\[ \partial_t \rho_t^\epsilon(u) = (L - \kappa \tilde{\Delta}_0^{1+\epsilon}) \rho_t^\epsilon(u) + \kappa \tilde{V}_0^{\alpha, \beta}(u) \]

starting from $\rho_0(u)$ and with Dirichlet boundary conditions: $\rho_t(0) = \alpha$, $\rho_t(1) = \beta$.

Above $L$ is the regional fractional laplacian and its action on functions $g \in C_\infty(0, 1)$ is given on $u \in (0, 1)$ by

\[ (Lg)(u) = c_r \lim_{\epsilon \to 0+} \int_0^1 1_{[u-v] \geq \epsilon} \frac{g(v) - g(u)}{|u-v|^{1+\gamma}} dv \]

and

\[ \tilde{V}_0^{\alpha, \beta}(u) = c_r \left( \frac{\alpha}{u^{\gamma}} + \frac{\beta}{(1-u)^{\gamma}} \right). \]

The hydrodynamic limit is then a Law of Large Numbers for the empirical measure. The natural questions that arise after solving this issue are related to the Central Limit theorem. In that case, the macroscopic law that we want to obtain is, in fact, a stochastic PDE which describes the fluctuations around the mean profile.

Typically the questions are the ones below:

What are the fluctuations around the mean for each one of these models? Is there some pattern of the macroscopic equations depending on the microscopic jump rates? Are there universality classes so that all the models (with general features) belong to? If so, what is the relation between these universality classes? Are these equations linked by some parameter that depends on the underlying dynamics?
Fluctuations:

In order to study the fluctuations of the exclusion processes defined above, we can consider that the process starts from an invariant measure. This measure has no evolution in time by the dynamics, that is if \( \eta_0 \) has law \( \mu \) then the law of \( \eta_t \) is again \( \mu \) for any time \( t > 0 \).

To simplify the exposition we can suppose in the exclusion dynamics defined above that \( \alpha = \beta = \rho \) and in this case, the invariant measures for those processes are the Bernoulli product measures which are parametrized by a constant \( \rho \) (that we denote here by \( v_\rho \) and that are defined by:

\[
v_\rho \{ \eta(x) = 1 \} = \rho.
\]

Then we define, what is called the density fluctuation field, which is a linear functional defined on a function \( f \), living in some proper space of test functions, as, for example, the Schwartz space, in the following way: first we integrate \( f \) with respect to the density empirical measure \( \pi^n_\eta(\eta, du) \), then we remove its mean (with respect to the invariant state) and then we multiply it by \( \sqrt{n} \) (so that we are in the Central Limit Theorem scaling), to get

\[
\Phi^n_\eta(f) = \frac{1}{\sqrt{n - 1}} \sum_{i=1}^{n-1} f(\frac{i}{n}) \pi^n_\eta(\eta_{\theta(n)}(x) - \rho).
\]

Note that above \( \rho \) is the mean of \( \eta_{\theta(n)}(x) \) with respect to \( v_\rho \).

At this level, the goal consists in obtaining the stochastic PDEs ruling the evolution of the limiting process of the sequence \( \{ \Phi^n \} \), denoted by \( \Psi \) (which is obtained from \( \{ \Phi^n \} \) in a proper topology by sending \( n \) to infinity).

Depending on the prescribed dynamics we can derive, from different underlying stochastic dynamics, different stochastic PDEs using this procedure. This brings a physical motivation for the study of the stochastic PDEs that will emerge from microscopic dynamics.

For the exclusion processes introduced above, we can get for:

1. the SSEP and re-scaling time diffusively \( t \theta(n) = n^2 \) - the Ornstein-Uhlenbeck equation (OUE) given by

\[
\partial_t \Psi_t = \Delta \Psi_t + \sqrt{\rho(1-\rho)} \nabla \Psi_t
\]

with the same boundary conditions as in the hydrodynamics level, see [10].

2. For \( \gamma > 1/2 \) and \( \theta = 0 \), the \( \gamma \)-WASEP and by re-scaling time diffusively \( t \theta(n) = n^2 \) the same OUE as in the previous item. This means that the asymmetry is not that strong in order to have some impact at the macroscopic level, so that the limiting equations are the same as in the symmetric case [11].

3. For \( \gamma = 1/2 \) and \( \theta = 0 \), the \( \frac{1}{2} \)-WASEP and by re-scaling time diffusively \( t \theta(n) = n^2 \), the Kardar-Parisi-Zhang equation (introduced in [1])

\[
\partial_t h_t = \Delta h_t - 2(\nabla h_t)^2 + \sqrt{\rho(1-\rho)} \Psi_t
\]

or its companion, namely the stochastic Burgers equation

\[
\partial_t \Psi_t = \Delta \Psi_t - 2 \nabla \Psi_t^2 + \sqrt{\rho(1-\rho)} \nabla \Psi_t
\]

depending whether one is looking at the height fluctuation field or the density fluctuation field, see [12, 11]. Above \( \Psi_t \) is a space-time white noise.

“This brings a physical motivation for the study of the stochastic PDEs that will emerge from microscopic dynamics.”
In [13, 14] it was proved that for a large class of weakly asymmetric simple exclusion processes without reservoirs, depending on the range of the parameter $\gamma$, the density fluctuations cross from the OUE to the stochastic Burgers equation. More precisely, in a phase of weak asymmetry ($\gamma > 1/2$), the density fluctuations are given by an OUE (the same OUE as in the SSEP). This means that in this regime, the asymmetry is not seen at the macroscopic level. Nevertheless, in a phase of strong asymmetry ($\gamma = 1/2$), the density fluctuations are given by energy solutions of the stochastic Burgers equation. Therefore the $\gamma$-WASEP crosses from, what is called, the Edward-Wilkinson universality class to the KPZ universality class, by changing the value of the parameter $\gamma$, which rules the strength of the asymmetry.

Making the connection with the tetris game that we have seen in the beginning of this report, the exclusion process is an example of microscopic stochastic model for which by tuning the parameter $\gamma$, that rules the strength of the asymmetry, it crosses for $\gamma > 1/2$ from the universality class of the Ornstein-Uhlenbeck process, which is related to the usual tetris game, to the case $\gamma = 1/2$ and to the KPZ universality class which is related to the sticky tetris game. Moreover, by tuning the strength of the reservoirs it also provides a transition between macroscopic laws (either PDEs or stochastic PDEs) with different boundary conditions.

Further Issues

One of the main open problems related to the issues presented above concerning the exclusion process is to obtain the limiting process when the asymmetry of the model is stronger than the symmetry.

Other important issue for other types of dynamics is to derive other universality classes and other stochastic PDEs that connect them, as happens for the stochastic Burgers equation connecting the Edward-Wilkinson universality class and the KPZ universality class.

“The expected results will contribute towards a better understanding of long standing problems in mathematical physics.”

Along these lines we have mentioned one type of dynamics, the exclusion process, which conserves one quantity, the density, but there are more complicated dynamics which can conserve more than one quantity of interest. In that case we can obtain systems of PDEs or systems of stochastic PDEs which can be coupled and different universality classes than those mentioned above. The Kardar-Parisi-Zhang and the Stochastic Burgers equation are therefore one example of equations connecting two different universality classes but many other are still to be explored.

Nowadays, there is a vast and intense field of research on these topics, but, due to its complexity and difficulty, the results have been derived almost model by model, equation by equation with many results.
given at an heuristic level and, some of them, obtained by computational simulations. Therefore, a rigorous mathematical proof of these results is lacking and the expected results will contribute towards a better understanding of long standing problems in mathematical physics.

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References


Optimization of buckling for textiles

Textiles are structures of fibers or yarns of arbitrary complexity, which also gives rise to the manifold usage of textiles in nearly every situation. Especially their flexibility standing in contrast to their durability is remarkable, but in some situations also a drawback. In particular this may result in unwanted behaviors like the buckling of a textile under special movements or constraints. For instance the buckling is an effect regularly present and possibly leading to critical effects, but not describable in an easy manner.

The following article about buckling textiles and their optimization arises from various industrial applications and is still under investigation. The research group is located at the Fraunhofer Institute for Industrial Mathematics in Kaiserslautern, Germany.

Problem description

Textiles are nearly everywhere present and used in many different areas with very different requirements. Various applications, of which some are diametrically opposed with respect to its functionality, imply diverse designs in both, microscopic and macroscopic characteristics.

The problem coming from industry is the buckling of textiles in special processes, which might not be wanted either out of cosmetical or productional or even safety critical reasons. There are plenty more reasons for many other applications and also different textiles and their demands. Hereafter we restrict to the buckling of a textile strap in the lateral direction. This buckling arises either from a tension in longitudinal or a compression in lateral direction. The goal of this project is the simultaneous retardation of the buckling and the optimization of its shape. By the shape optimization here it is meant that the buckling-shape is close to a given profile such that no further complications arise in the subsequent events.

Figure 1: Textile patch in canvas structure consisting of carbon fibers.

Important to realize here is that textiles are very complex structures consisting of fibers or yarns. This gives rise to the design space in which the properties and also their
weaving structure can be chosen during the optimization procedure.

**Modeling**

To model this problem described above we assume the textile to be a heterogeneous 2D-plate and use therefore the nonlinear von-Kármán-plate model. In fact, due to the symmetries of the textile and the use of an uniaxial force, this model can be further reduced to a linear, one dimensional fourth order equation

\[ \Delta(B(x))\Delta u - F\Delta u = 0, \quad (5.1) \]

Here \( F \) denotes the lateral compressive force (or the diverted tensional force), \( B(x) \) is the heterogeneous bending stiffness, depending on the microscopic design and \( u \) the out-of plane displacement of the belt. To complete the problem (5.1) we use the boundary conditions

\[ u(\pm L) = u_s(\pm L) = 0, \quad (5.2) \]

for the textile width of \( 2L \).

In fact equation (5.1) has two regimes with very different results. The first regime results from \( F \geq 0 \), where the only solution \( u \equiv 0 \) to this equation is trivial. The second regime arises from \( F < 0 \), which corresponds to the compressive case. In fact this is the interesting case and it further divides into two regimes. The problem again is uniquely solvable for \( |F| < F_{cr} \), with \( u \equiv 0 \), but as soon as the critical force \( |F| = F_{cr} \) is reached, the textile buckles. Since the retardation of the buckling directly corresponds to the maximization of \( F_{cr} \), it is obvious that it is crucial to identify this critical force. Assuming \( B \) to be overall constant, it turns out that this critical force corresponds to a generalized eigenvalue of the system and yields

\[ \lambda_B = \frac{B\pi^2}{4L^2} - F, \quad (5.3) \]

wherefrom we derive the critical force

\[ F_{cr} = \frac{B\pi^2}{4L^2}. \quad (5.4) \]

Hence, maximizing \( B \) or minimizing \( L \) leads to a higher critical force and thereby a retardation of the buckling. By the relation (5.3) it is obvious that a maximization of \( \lambda_B \) corresponds directly to a maximization of \( F_{cr} \), but it is easier to derive. In fact, if \( B \) is not constant this is a bit more involved but can be handled by a generalized Rayleigh-quotient argument to compute \( \lambda_B \) for constant \( F \). The shape-optimization of the buckling mode is then rather easily added, since it is the corresponding eigenmode to the above Rayleigh-quotient.

Those two considerations give rise to the objective functional

\[ J(u) = \gamma||u - u_0||_{L^2((-L,L))} + (1 - \gamma)\lambda_B \quad (5.5) \]

for the optimization, where \( u_0 \) is the desired shape of the buckling mode and \( \lambda_B = \lambda_B(F_{cr}) \) the generalized eigenvalue. Here we added an additional factor \( \gamma \in [0,1] \), which is suitable to weight the two terms in the objective function. For instance this factor allows to balance the terms and also gives the possibility to manage the Pareto-efficiency.

Finally note also that the bending stiffness depends on the material and the inherent structure of the textile and is obviously restricted and bounded. This leads to the additional constraint

\[ 0 < b_1 \leq B(x) \leq b_2, \quad (5.6) \]

where \( b_1 \) and \( b_2 \) are given by the manufacturing process. Moreover, it is often interesting to preserve the mean value of \( B \) or at least only small deviations from it. This leads to

\[ \frac{1}{2L} \int_{-L}^{L} B \, dx = M_B, \quad (5.7) \]

where \( M_B \) is a predefined mean value to achieve.

The last constraint is the symmetry of the product. This means that the final textile is a product symmetric with respect to \( x = 0 \), meaning that the resulting bending stiffness
\( B_{opt} \) is also symmetric with respect to this axis.

**Results**

The discussed model is implemented in Matlab and the optimization is done by a Matlab internal optimizer. The most crucial ingredient to control the problem above towards a desired solution is the factor \( \gamma \). To emphasize this, we show below two different computations where one sees directly what effects a slight modification of this factor can have. Beside \( \gamma \) all other parameters maintain constant in both simulations. The bending stiffness \( B(x) \) is bounded from below by \( h_1 = M_B / 10 \), i.e. the lowest value for \( B(x) \) is 10% from the initial bending stiffness. Furthermore, the mean bending stiffness can differ at most 10% from its initial constant value \( M_B = B_{init} \). As further adaptation, the bending stiffness is divided into 20 piecewise constant sections, being symmetric with respect to \( x = 0 \). The piecewise constant character of the bending stiffness corresponds to one or more fibers with the same properties and thus the same resulting bending stiffness in such a section.

In the following example the goal-shape \( u_g \) is chosen to be flat at the ends for 20% of each side of the sample. This corresponds to a higher overall amplitude, but a lower one at the lateral boundaries of the sample.

**Simulation 1**

For the first simulation the factor \( \gamma = 0.98 \) is chosen to balance both terms in the objective functional \( J(u) \). This means that both the shape-optimization and the retardation are taken into account and optimized. In Figure 2 the objective functional and the two terms within are depicted. The value \( \lambda_B \) responsible for the retardation is improved by more than 15% while the second part even achieves a more than 45% better result than before the optimization.

![Figure 2: Simulation for \( \gamma = 0.98 \). From top to bottom: Development of the function value of \( J_B(u) \), the eigenvalue \( \lambda_B \) and the distance to the goal function \( u_g \) during the optimization.](image)

Figure 3 shows the effect of the optimization. In the top figure we see that the shape of the buckling transforms from an initially (blue) quite bad similarity to a more fitting shape (red) being closer to the desired shape \( u_g \) (green) in the end. The second graph shows how the bending stiffness \( B(x) \) is optimized from a constant function to a step function, which is stiffer at the ends and rather soft in its middle of the textile.

![Figure 3: Simulation for \( \gamma = 0.98 \). Top: The first Buckling modes for the initial and the optimized problem with the desired buckling-shape \( u_g \).](image)
Over the whole textile the mean bending stiffness has reached its maximum of 110% of $M_B$.

Simulation 2

The second simulation uses $\gamma = 0.995$ and thus weights the buckling-shape optimization a bit more than the retardation. Although the difference between the values of gamma is not very big, the change in the result is noticeable. Here the buckling-shape is improved by almost 75% with the cost that $\lambda_B$ is even reduced by 3%.

Concluding the second simulation, we see that also the resulting optimized bending stiffness and shape look different. As expected from Figure 4 we see that the final shape is very close to the desired one. Also, $B_{opt}$ is evidently changed, e.g. the maximal stiffness is no longer at the ends of the textile, and the mean value is now increased by only 6% instead of 10% in the first example.

Conclusions

In the presented case, the buckling of textiles, we were able to find a heterogeneous bending stiffness, which can be adapted via $\gamma$ to the optimal needs of the later product. Further customizations like other desired shapes or additional demands can be applied.

Both simulations show the versatility and efficiency of this optimization. Additionally, this simulative approach saves a lot of work in comparison to trial and error procedures, to obtain textiles with higher quality and better adaption to their demands.

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References


Dynamics of the capillary rise: a peculiar occurrence of oscillations

Capillary rise in a narrow vertical tube is a remarkable physical phenomenon that can be observed in many everyday situations. One of the most common natural examples of capillary action is water transport in soil or plants. Moreover, its applications can readily be found in various industrial processes like inkjet printing. Despite of the complexity of this phenomenon at the molecular level, the fluid-dynamical approach allows for a systematic and accurate analysis. For instance, we are able to prove that there exists a critical value of the fundamental dimensionless parameters at which the capillary motion undergoes a transition from being monotone to oscillatory. In this article we give an exposition of this peculiar phenomenon.

Problem description

Mathematical models describing the behaviour of a liquid in a narrow tube were posed and extensively studied in the last few decades. However, the initial steps in describing capillary action were made much earlier by Washburn [1]. His model was based on an approximate differential equation describing the balance between gravity and capillary pressure in a narrow tube. In what follows we analyse a singular second-order nonlinear ODE that takes into account some other factors and can be thought as a generalization of Washburn’s equation.

Capillary rise is a movement of a liquid due to upward force caused by interaction of the fluid molecules with the surrounding surface. Parallel to the theoretical modelling, many experiments (see [2, 3]) discovered that for certain liquids we can observe free boundary oscillations near the equilibrium point (level of the liquid after a very long time) while for other - simple monotone increase of their height.

Authors distinguish two dynamical regimes of the fluid flow in a capillary rise experiment: gravity dominated case and viscosity dominated. Those regimes correspond to the situations where the fluid column height either increases or oscillates near the Jurin’s height. The occurrence of...
these two situations depend on the ratio of two dimensionless quantities, namely Ohnesorge and Bond numbers. Experiments show that there exists a critical value of the dimensionless parameter which distinguishes those two behaviours.

It can be checked that the Reynolds’ number at the beginning of rise is low hence the flow is laminar. Initial conditions are set by entrance effect only. It was experimentally and theoretically proved that the initial velocity is equal to zero while the height starts increasing from a small positive value [4]. On the other hand, it seems natural to assume that the fluid is initially at rest with zero height but physically this not the case. A more adequate choice of the initial conditions, which is confirmed by the experiment, is setting the height to be equal the mass of a liquid entrained below the pipe. Additionally, in [5] it was analytically shown by using the energy balance that the initial acceleration can not be infinite.

Mathematical model

We consider a tube with small radius \( r \) of its cross-section. It is put into a contact with a liquid container. The walls of this bath are in some distance from the tube so we will not consider any perturbation of the flow caused by them. To find the governing equation describing the capillary rise in tube we need to take into account all the forces that act on a volume of the liquid. Of course, the upward force that is responsible for the movement of fluid have to be strictly associated with the surface tension \( \gamma \) and with contact angle \( \theta \). The other forces caused by the gravity and viscosity inhibit the flow

\[
\frac{8\mu}{\sqrt{r}} \frac{dh}{dt} + \frac{\rho g h}{r} + \frac{d}{dt} \left( \frac{d}{dt} (h^2) \right) = \frac{2\gamma \cos \theta}{r},
\]

where \( h = h(t) \) is a liquid column height at time \( t \), \( \mu \) is the viscosity, and \( \rho \) is the density. We will say that the liquid attains the Jurin’s height if

\[
h(t) = \frac{2\gamma \cos \theta}{\rho g r} =: h_c,
\]

or in other words, when the capillary force balances the weight of the liquid.

As was mentioned above, the most natural choice of the initial conditions is based on an assumption that at the beginning of the experiment the fluid velocity is zero and the height of liquid has a positive value (this corresponds to the mass of a liquid that is initially accelerated). For simplicity of calculations we are considering a slightly different initial conditions, namely

\[
h(0) = 0, \quad h'(0) = \sqrt{\frac{2\gamma \cos \theta}{\rho g}},
\]

These conditions arise from the requirement that \( h(0) = 0 \) and the consistency of the governing equation. It is worth emphasizing that the other popular choice of initial conditions \( h(0) \neq 0, h'(0) = 0 \) does not affect the final results.

To reduce number of constants involved in the governing equation we can cast it into the dimensionless form. The proper scales for height \( h \) and time \( t \) are respectively: \( h_c \), defined before, and \( \tau = \frac{\gamma r}{\rho g r^2} \). Therefore,

\[
HH'' + H = \omega (HH')' = 1,
\]

with the initial conditions

\[
H(0) = 0, \quad H'(0) = \frac{1}{\sqrt{\omega}},
\]

and the dimensionless parameter

\[
\omega = \frac{\rho^2 g r^4}{64 \mu^2 h_c^2}.
\]

As it turns out the quantity \( \omega \) has a significant influence on the behaviour of the liquid.

Results and discussion

Having the governing equation in the non-dimensional form we can proceed with further analysis of this nonlinear second order differential equation. In [6] the theoretical methods were applied to ensure
that the problem is well posed. We proved existence and uniqueness of the solution to (5.11) and obtained the exact form of energy function

\[ E(s) = \frac{1}{2} u'(s)^2 - u(s) + \frac{2\sqrt{3}}{3} u(s)^{3/2}, \]  

(5.14)

where \( u(s) = \frac{1}{2} H(s\sqrt{\omega})^2 \) and \( s = T/\sqrt{\omega} \). It can be shown that \( E(s) \) is nonincreasing with \( E(0) = 0 \). This implies the fact that the energy is dissipated outside the system. Moreover, an utilization of the equivalent integral equation along with the energy method can be used to find the asymptotic behaviour for small times

\[ h(t) = \frac{H_T}{\sqrt{\omega}} t + O(t^2) \quad \text{as} \quad t \to 0^+. \]  

(5.15)

Therefore, the height of liquid for small times increase linearly with time.

It is easy to see that after a long time, the height of liquid will reach the Jurin’s height and at the same time, the velocity of the flow will be very small (by the energy relation (5.14)). In order to study the liquid behaviour near the critical point \((h_0, h'_0) = (h_c, 0)\) we will use the dynamical systems approach. Experiments conducted by others authors (for ex. [2, 3]) provide us with a data giving the change of the height with time. For various values of the nondimensional parameter \( \omega \) the experiments give different data graphs. For example, for diethyl ether (see [3]) the oscillation behaviour is observed an we can calculate that \( \omega = 11.57 \). On the other hand, for the experiment with the silicone oil we have \( \omega = 1.7 \times 10^{-6} \) and observe the monotone flow only.

The main question arises: is it possible to deduce the conditions for oscillatory or monotone regimes from the governing equation? We will show that the answer to this question is affirmative and the sought transition is determined from the physical properties of the liquid and the value of the cross-sectional radius of the tube.

To apply the dynamical system approach let us construct a system of first ODEs. Introduce the new variables \( x(t) = u(t) = H^2(T/\omega) \) and \( y(t) = u'(t) \), then (5.11) transforms into nonlinear ODE system:

\[
\begin{align*}
x' &= y, \\
y' &= 1 - \frac{1}{\sqrt{\omega}} y - \sqrt{\omega x}, \quad x \geq 0.
\end{align*}
\]  

(5.16)

After linearisation near the critical point, we compute the eigenvalues

\[
\lambda_{1,2} = \frac{-1 \pm \sqrt{1 - 4\omega}}{2\sqrt{\omega}}. \]  

(5.17)

We conclude that for \( \omega > 0.25 \) the eigenvalues are complex conjugate and thus we observe oscillatory behaviour near the critical point. Consequently, the monotone behaviour is present for \( \omega < 0.25 \). Moreover, the real part of the above is always negative hence the point is always locally stable. We also notice that both oscillatory or monotone regimes are independent of choice of initial conditions. This critical value of \( \omega \) is consistent with the experimental evidence mentioned earlier.
To give a stronger stability result we can estimate the size of the basin of attraction. To this end we construct the Lyapunov function
\[ V(x,y) = \frac{1}{2}y^2 + x - \ln x - 1, \quad (5.18) \]
which is nonincreasing and positive-definite on the set $\Omega := \{(x,y) \in \mathbb{R}^2 : y \geq -\varepsilon x\}$. To show the asymptotic stability we have to find an invariant set contained in $\Omega$. Then, by the LaSalle’s Invariance Principle this assertion will hold. For example, this set can be the interior of the level-curve of $V$ that is tangent to the line $y = -\varepsilon x$. Some examples are depicted on Figs. 3 and 4. We can see that although all the trajectories that enter the dark grey set always stay within it, there are some others that elude this characterisation. This is one of the subjects of our future work - to provide some better estimates on the basin of attraction.

### Conclusions

A classical model for capillary rise can be written as a singular second-order nonlinear equation. As it appears, its unique stationary point is asymptotically stable and undergoes a change in its behaviour. As the nondimensional parameter increases through its critical value, the eigenvalues gain nonzero imaginary part what initializes oscillations. This phenomenon has been thoroughly verified by the experiment and our analysis gives the rigorous proof of it.

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### References

Mathematical Algorithms for MICADO – First Light Instrument at the European Extremely Large Telescope

Modern ground-based telescopes like the planned Extremely Large Telescope (ELT) aim for better images of very faint objects on the night sky, and therefore, use advanced techniques to correct for any image degradation. Adaptive Optics (AO) is a technique to compensate for atmospheric distortions of the incoming light. However, a perfect image is still not achievable due to, e.g., time delays within these correction processes. This results in a blur which can be mathematically described by a convolution of the true image with the point spread function (PSF). The PSF associated to an astronomical observation can be reconstructed from data acquired during run time by the AO system. Furthermore, the reconstructed PSF can then be used for improving the image in blind deconvolution as a post-processing step. We present the development of algorithms for these problems in the context of the ELT first light instrument MICADO.

In this article, we present the reasons for developing mathematical algorithms in ground-based astronomy, in particular for the ELT first light instrument MICADO [1], which is under construction. As members in the MICADO Consortium, the Industrial Mathematics Institute at Johannes Kepler University (JKU) and the Johann Radon Institute for Computational and Applied Mathematics (RICAM) of the Austrian Academy of Sciences (AAS), both based in Linz, Austria, are involved in designing new
algorithms to tackle the challenges of an extremely large telescope as part of the Dataflow team led by the Kapteyn Astronomical Institute at the University of Groningen in the Netherlands and the Institute for Astrophysics at the University of Vienna. The MICADO Consortium is led by the Max Planck Institute for Extraterrestrial Physics (MPE) at Garching, Germany.

What is MICADO?

The name MICADO is well-known in a slightly different spelling, Mikado, as a pick-up sticks game and was used to entitle the Japanese emperor. Within the European ELT, MICADO is an imaging instrument focusing on high precision astrometry and spectroscopy, equipped with a Single-Conjugate AO (SCAO) system. Optimized for imaging at the diffraction limit at wavelengths from 0.8 to 2.4 µm with high angular resolution, MICADO will allow discovery and study of new or unexplored phenomena, such as the detailed structure of galaxies at high redshift, the study of individual stars in nearby galaxies and exoplanets. The MICADO instrument shall see first light in 2024.

In a second step, MICADO will be coupled to MAORY, the Multi-conjugate Adaptive Optics RelaY for the ELT, which will provide a more uniform correction over the field of view and make use of atmospheric tomography.

Mathematics in ground-based astronomy

In ground-based astronomy, the observed image \( I_o \) can be described as a convolution of the true image \( I \) and the so-called point spread function (PSF), i.e.,

\[
I_o = I \ast \mathcal{P} \mathcal{F}.
\] (5.19)

The PSF of an astronomical observation through a ground-based telescope depends on the one hand on the geometry of the telescope and the atmospheric turbulence above the telescope and on the other hand on the design of the instrument, in particular aberrations by its optical components (see Figure 1). Modern ground-based telescopes reduce the effect of the rapidly changing turbulent atmosphere by using Adaptive Optics systems (cf [2]). AO systems consist of three main parts: one or more wavefront sensors (WFS), one or more deformable mirrors (DM) and a real time computer (RTC). The task of the RTC is to transform indirect measurements made by the WFS into commands applied to the DM. By adapting the shape of the DM the incoming wavefront of the light is altered in such a way as to counter the aberration introduced by the atmospheric turbulence. MICADO will, as a modern instrument, be equipped with such an AO System to obtain superior image quality to the NASA/ESA James Webb Space Telescope. However, the AO system can not fully correct for the effects caused by atmospheric turbulence, especially due to a time lag and limited resolution of the WFS in the system, resulting in a PSF still degraded by residual atmospheric turbulence as well as telescope and instrument intrinsic effects (see Figure 2). As a consequence, the observed image appears blurred.
acquired by the WFS and the commands applied to the DM after the image has been obtained. Availability of the PSF allows to access parameters which determine the quality of an observation, without estimating them from the science image. Additionally, the PSF can be used for image improvement in a post processing step, such as deconvolution.

### Estimating the blur of observed images

Throughout the past years several algorithms for reconstructing the PSF from WFS data and DM commands were developed [3, 4, 5, 6] and some even tested on sky [7, 8, 9, 10, 11]. The common basic ingredient is the calculation of the so-called structure function \(D\), i.e., the time averaged spatial correlation of an incoming phase \(f\) after AO correction,

\[
D_f(r) = \langle (f(x,t) - f(x + r, t))^2 \rangle_t, \quad (5.20)
\]

where \(\langle \cdot \rangle_t\) indicates the time average and \(x, r\) are spatial coordinates within the telescope aperture. The phase \(f\) is related to the incoming wavefront \(\varphi\) through the wavelength \(\lambda\) as \(f = \frac{2\pi}{\lambda} \varphi\). The structure function is related to the PSF as,

\[
\mathcal{P} \mathcal{F} = \mathcal{F} \left( \frac{1}{S} \int \mathcal{P}(x) \mathcal{P}(x + \rho) e^{-\frac{1}{2}D_f(x, \rho)} dx \right), \quad (5.21)
\]

where \(\mathcal{F}\) denotes the Fourier transform, \(S\) the area of the telescope pupil and \(\mathcal{P}\) the indicator function of the telescope aperture. However, most of the existing algorithms are computationally demanding as they make use of global basis functions, such as Zernike polynomials. Their use seems to be not feasible for increasing sizes of the telescopes.

We adopted the algorithm of [3] by using bilinear splines in order to decrease the computational costs and make an implementation feasible for the ELT [12, 13]. Furthermore, we split the approach into two parts: First from WFS data we reconstruct the incoming wavefront on our bilinear spline basis, second we compute from this wavefront the covariance matrix used for further calculation. In the original method, the covariance matrix was calculated directly on measurements and then transferred to wavefront level by using an interaction matrix (and its transpose), resulting in a computational complexity of \(O(N^2)\) for \(N\) measurements. We can use a matrix-free wavefront reconstruction algorithm, and thus, decrease the computational costs to \(O(N)\).

Our algorithm delivers a reconstructed PSF in the direction of a so-called guide star, which is a star being bright enough to get reliable WFS measurements. For SCAO systems, the correction of atmospheric turbulence is only valid for this line of sight. However, the object of interest might be in a significantly different position in the sky image, resulting in a different atmospheric distortion, and hence, less correction through the AO system. Thus, spatially varying estimates for the PSF are needed. We are investigating new algorithms to obtain accurate PSF estimates also for these cases. For more complex AO systems, such as MAORY, having more guide stars, a field dependent estimate of the PSF can be provided by using atmospheric tomography algorithms such as [14, 15].

### Improving images in a postprocessing step

The PSF of an observation does not only serve as a quality measure for the AO correction, but it can also be used for image improvement in a post-observational procedure. Mathematically speaking, a convolution of the true image and the PSF gives the observed image. We illustrate how an image of a star cluster (Figure 3) is blurred when observed through a ground-based telescope even with AO correction in Figure 4. The estimate of the PSF shall help to compensate for this blur by using a postprocessing step.
Having an estimate for the PSF, the observed image can be improved by using a deconvolution algorithm. Due to effects related to the AO system and instrument intrinsic aberrations, the estimate for the PSF might not be accurate enough for directly improving the observed image by deconvolution. We are now developing blind deconvolution algorithms (cf [16]), allowing for changes in the PSF and taking care of specific available information on the observed stars. This will result in improved images (see Figure 5) where very faint objects can be detected.

Figure 3: True image of a star cluster (i.e., not altered by a PSF, which corresponds to using an infinitely large telescope without atmospheric aberrations). Credit: Kirk Soodhalter.

Figure 4: Blurred Image. Credit: Kirk Soodhalter.

Figure 5: The effect of deconvolution is clearly visible. Credit: Kirk Soodhalter.

Conclusions

We developed algorithms for PSF reconstruction needed for new instruments at ELTs using astronomical adaptive optics and tested them in an idealized simulation. As next steps, we need to adjust the simulation step by step to real life, e.g., by incorporating the real structure of the primary and secondary mirror of the telescope. We also want to verify our algorithms on real observations of existing AO assisted instruments. Furthermore, we expect that our algorithms will need further development to account for aberrations of other parts of the optical system of telescope and instrument once manufactured and assembled. We anticipate that this requires to invent strategies for measuring these aberrations and devise ways to incorporate.

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References


I am an associate professor in applied mathematics at University of Grenoble since 2009. As such I have, I have participated in different kind of teaching activities. Grenoble have been involved with ECMI for a long time and some several of my colleagues participated to modelling weeks as instructor. Having heard of the goal and spirit of the modelling weeks, I considered the challenge to be interesting.

In July 2017, I had the opportunity to take part of the modelling week in Lappeenranta. The problem I submitted to the students dealt with the study and determination of fundamental state if matter. The objective was to propose different computational approach that help to determine the pseudo-stable states in classical frustrated spins. For example, in triangle lattice of Ising spins, one third of the spins cannot gain energy from its neighbors, hence the stable states are computationally difficult to discover.

The team that work on the project consists of third year bachelor student, first year master students and students that were abut to start their PhD. None of them were familiar wit the subject or the mathematical tools needed to solve the problem. Hence, several session of discussions and brainstorming were needed to get acquainted with the physics, the possible models and the numerical tools to solve the problem. It was very interesting to see the team seize the subject and their way to model new computational approach. By the end ot the week, I believe the students had a good understanding of the problem and the solution proposed was really well thought.

Before coming to the modelling week, I didn’t really know what to expect. After spending a week working with students from all over Europe, my opinion is as an instructor the challenge is not only to pose the problem but also to guide the students to formulate their own solutions without biased. You need to find a balance between the time spend with the students to help them come up with specific items and the time they need to come up with solutions. The range of scientific background and skills in the students concur to make this week rewarding.

The time spends with students and other instructors out of the work session was also fruitful. I believe it helps to give a glimpse on how each educational systems work and how to improve the teaching of applied mathematics in our local universities.

Overall, my participation to this modelling week was a good experience. It provides me with some ideas on how to suggest such modelling weeks in France. And also, I will gladly participate to another modelling week.

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Figure 1: Verona and the Arena

The University of Verona was founded in 1982, has around 24,000 students and is organized in one downtown campus hosting the departments/faculties of the human and social sciences area (Business Administration, Culture and Civilisation, Economics, Foreign Languages and Literatures, Human sciences, Law) and in one suburb campus hosting the School of Medicine (with the Departments of Medicine, Neurosciences Biomedicine and Movement Sciences, Surgery Dentistry Pediatrics and Gynaecology, Diagnostics and Public Health) and the School of Science and Engineering (with the Departments of Biotechnology and Computer Science). There are around 60 Bachelor Degree, 60 Master Degree and 17 PhD programs. Faculty members are around 1100, administrative staff counts 900 people. Concerning internationalization, there are around 45 cooperation agreements with EU and non EU Universities, 250 Erasmus+ agreements, 3 Double Degrees, 6-7% of international students. There are funded mobility programs (Short Term Mobility, World Wide Study) besides Erasmus+ and Erasmus+ for Traineeship, moreover there is a strongly funded Internationalization at Home program, with six Master Degrees entirely taught in English (Economics, Mathematics, Linguistics, Medical Bioinformatics, Biotechnologies, International Economics and Business Management), with many invited international teaching faculties.

Concerning research and technological transfer, the University of Verona runs specific funding programmes for both projects in Fundamental Research and joint research Projects with industries, supporting innovation processes and the creation of networks in the lively SME environment at a regional level also through start-up and spin-off companies.

Department of Computer Science

Figure 2: the Department of Computer Science

The Department of Computer Science of the University of Verona embraces a continuum of research areas in computer science, computer engineering, mathematics and physics, ranging from discrete and computational mathematics, mathematical modelling and applications, machine intelligence, information systems, software engineering and security, cyber-physical systems, to applied and experimental Physics with almost 70 permanent faculty and research staff. It has been recently awarded the Italian Ministry of Education Project "Departments of Excellence" to implement specific research and educational activities oriented to the Industry 4.0 world. The Department,
together with the School of Science and Engineering is in charge of 3 BSc degrees (Computer Science, Applied Mathematics, Bioinformatics), 3 MSc degrees (Computer Engineering, Mathematics, Medical Bioinformatics) one PhD program in Computer Science and one PhD program in Mathematics in agreement with Trento University. It hosts a Computer Science Park, an entity for technological transfer with several spin-off and start-up.

Math educational programme

The 3 years BSc in Applied Mathematics is articulated in two main educational paths: one focuses on economics and financial math, while the other is a modelling and computational one. The MSc in Mathematics is entirely taught in English and consists in two curricula: one is mathematics for teaching, the other one is applied and industrial mathematics, and fulfills the requirements of the ECMI Master Model. Main educational paths are in mathematical finance and data science, mathematical modelling in the applied sciences, numerical methods and scientific computing. Every year several international invited faculties through the Internationalisation at Home program, coming also from other ECMI nodes, give many interesting complimentary courses. This motivates students to spend semesters abroad within Erasmus+ mobility (more than 20 partner destinations and several ECMI nodes), even for internships and master thesis. Many contacts with banking, industries and scientific laboratories (biomedicine, robotics, virtual simulations, artificial intelligence) at regional and national level give students very good opportunities for internships, industrial master thesis and placement. Finally, a joint PhD program with the University of Trento on both pure and applied math topics is also running well, with several educational events involving also master students, like for instance summer schools and modelling weeks.

Figure 1: First PhD Modelling Week in Verona, Sept. 2016

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ECMI Special Interest Groups (SIGs)

Special Interest Groups (SIGs) exist to promote collaborative research on specific topics in Mathematics for Industry within Europe. A particular aim is to enable researchers from both academia and industry with similar interests to get together and submit proposals for funding to the European Union or to other funding bodies. ECMI can act as a catalyst in the formation of such a group by offering advice about the expertise available within Europe, by posting information on the web pages and by circulating information about events to all members.
Math for the Digital Factory

Purpose

The digital factory represents a network of digital models and methods of simulation and 3D visualisation for the holistic planning, realisation, control and ongoing improvement of all factory processes related to a specific product. In the last five or ten years all industrialised countries have launched initiatives to realise this vision, sometimes also referred to as Industry 4.0 (in Europe) or Smart Manufacturing (in the United States).

Opportunities

The Special Interest Group MaDiFa (Math for the Digital Factory) brings together university mathematicians working in modelling, simulation and optimization related to manufacturing with practitioners from manufacturing industry. The general scientific goal is to develop a holistic mathematical view on digital manufacturing. Topics to be discussed include:

- coupling of multibody systems with PDE models to describe interactions between machine tool (typically a MBS) and its manufacturing task (typically described by PDEs and ODEs)
- multiscale models of complex manufacturing chains including workflow
- new concepts to model the energy consumption of machine tools and more complex production systems
- optimization strategies for energy and material efficient production

Activities

In 2017 our main activities were focussed on finalizing a multi-author textbook on digital manufacturing, which finally was published in December 2017. It provides a unique collection of mathematical tools and industrial case studies in digital manufacturing, addressing various topics, ranging from models of single production technologies, production lines, logistics and workflows to models and optimization strategies for energy consumption in production.

For 2018 we plan 3 major activities. The next SIG workshop already took place in Limerick in March 2018. Then we will organize a minisymposium during the ECMI conference in Budapest. Finally, we plan to submit a proposal for a European Joint Doctorate for maths in digital manufacturing in the next ITN call.

Dietmar Hömberg

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Sustainable Energies

The ideas for this SIG originated with the “Mathematics in Industry” workshop “Technologies of thin film solar cells”, held in Berlin. It was followed by a series of workshops held in the UK and Germany with ever increasing scope from organic photovoltaics, supercapacitors, Lithium-Ion batteries, solar fuels and resulted in the Kick-Off meeting “Nanostructures for Photovoltaics and Energy Storage” for this SIG, which also included electrothermal modelling and simulation of organic materials and devices.

Purpose

We address the challenges posed by the way energy is being generated in the future, with a high demand for sources of sustainable energy and production capabilities and which entails the restructuring of existing as well as the creation of new, smart networks for efficient storage and transport of distributed energy. Mathematics plays a key role in understanding the complex problems that arise in these areas and in exploiting underlying structures and processes.

Opportunities

Researchers and non-academics eg. from industry working in fields such as thermoelectricity, nano-scale optics, organic/polymer electronics such as organic LEDs and storage systems are presently the key stake holders to which this SIG reaches with its activities. Contributions relating to energy distribution and networks are also welcome.

Activities

Several activities have achieved success and visible results:

- At the Weierstrass Institute, Manuel Lahnstorfer and Barbara Wagner (coordinating PIs) were successful with their proposal on second life batteries, bringing together mathematicians, engineers and four industrial partners. The background of the research is the idea to reuse Lithium batteries as stationary storage after they have been
retired from their primary use in electrical vehicles.

For the ECMI annual conference in Budapest, the SIGs activities are showcased in a minisymposium on “Material design and performance in sustainable energies”. Contributors will speak on solar cells, batteries, wind power, and connections to material science modelling.

Mathematical research plays an important role in the development of renewable energies, and hence makes a contribution to addressing the challenges raised by climate change and the phasing out of fossil fuels. In the context of photovoltaics, for example, the aim is often to optimize light management and charge transport and understand the interplay with the nano-morphology of the material, and how to make it. These were some of the topics which Barbara Wagner presented while speaking at an invited plenary lecture on “Mathematical Opportunities and Challenges in Sustainable Energies” at the SIAM Annual Meeting in Pittsburgh in 2017 (and coming up at the SIAM Conference on Nonlinear Waves and Coherent Structure).

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Computational
Finance

The ECMI Special Interest Group Computational Finance was launched at ECMI-2014 in Taormina (June 9–13, 2014) and (together with the ITN STRIKE Project) organized several sessions of a minisymposium in Computational Finance, e.g. at ECMI 2016 and ICCF-2017. The aim of the SIG is to extend the network and to build a framework to continue close cooperation in future. It also provides a long term professional contact option for Alumni of ITN-STRIKE. In 2018 the SIG is active at ECMI-2018 in Budapest and organizes a minisymposium entitled Computational Methods for Finance and Energy Markets.

Purpose

At ECMI-2018 the Special Interest Group on Computational Finance organizes a minisymposium Computational Methods for Finance and Energy Markets. We will bring together again twelve speakers coming from Universitas Indonesia Depok (Jawa Barat, Indonesia), "Pázmány Péter" Catholic University Budapest (Hungary), Fraunhofer Institute for Industrial Mathematics ITWM (Kaiserslautern, Germany), University of Southern Denmark (Odense, Denmark), Instituto Superior Técnico (Universidade de Lisboa, Portugal), Bergische Universität Wuppertal (Germany), Wroclaw University of Science and Technology (Poland), University of Sussex (Great Britain), Max Planck Institute for Mathematics in the Sciences (Leipzig, Germany) and Uniper Global Commodities (Düsseldorf, Germany). The minisymposium will address topics from Computational Finance, Computational Methods for Energy Markets and Risk Analysis.

The efficient production and use of energy, the development of new energy sources, and responsible management of the resources available to us now are critical for our future and need properly functioning markets. Mathematics has played a key role in the development of modern financial markets and risk management tools. Energy commodity and environmental markets differ in fundamental ways from markets for other asset classes. Some of the challenges in this research area involve the development of new stochastic models that can capture the extreme price movements in power markets. The tasks of asset valuation and the determination of optimal operation strategies in this context generate complex, high dimensional valuation problems for which new computational techniques must be developed. Changes in market mechanisms and products demand novel mathematical techniques, stochastic and deterministic models, microscopic and macroscopic approaches, and flexible pricing tools, defining innovative research areas in the field of applied mathematics.
Opportunities

The SIG will look for opportunities for new projects in both directions, Computational Finance and Energy Markets, in the coming years (ETN, EID, and EJD). The Special Interest Group is open for further participation.

Activities

Lorentz Center, Leiden, the Netherlands, see https://www.lorentzcenter.nl/lc/web/2017/907/info.php3?wsid=907&venue=Oort. Many companies from the energy sector participated actively and gave presentations, e.g. EnBW Energy (Karlsruhe, Germany), Uniper Energy, (Düsseldorf, Germany), KYOS (Haarlem, the Netherlands) Energy Quants (Amsterdam, the Netherlands) and N-SIDE (Louvain-la-Neuve, Belgium).

Key points addressed were:

(A) Risk management issues related to the energy transition,

(B) Energy derivatives facilitating the energy transition,

(C) Decisions for demand flexibilization in energy intensive industry.

Discussions were on the economics of the energy transition with mathematical models, on research questions from and with the industry and on in energy operations and energy derivatives.

On September 4-8, 2017, the conference ICCF 2017 - International Conference on Computational Finance (Lisbon, Portugal) was organized by Maria do Rosário Grossinho, see http://cemapre.iseg.ulisboa.pt/iccf2017/. Several people from the SIG, or from the former ITN-STRIKE project, were involved in committees and/or as invited speaker. With ICCF we have established a new series of conferences. The first one was held in Greenwich/London (2015). Next conferences will be in 2019 (A Coruña, Spain), 2021 (Wuppertal, Germany) and
In September the "STRIKE Book" (Novel Methods in Computational Finance), with outcomes of the ITN-STRIKE project (2013-2016) was published in the book series Mathematics in Industry at Springer. This book already turned out to be a great success. Since its online publication on September 20, 2017, there has been in 2017 a total of 11,964 chapter downloads for this eBook on SpringerLink. This means the STRIKE book was one of the top 25% most downloaded eBooks in the relevant eBook Collection in 2017. For more details on the SIG see our information on the ECMI Blog, https://ecmiindmath.org/2017/12/01/successful-outcomes-of- rtn-strike/. Additionally, a STRIKE Success Story was published on the CORDIS Server, and a press release was published by the University of Wuppertal, see http://ec.europa.eu/research/infocentre/article_en.cfm?artid=47876.

(Planned) Activities for 2018 and beyond


► Co-organize ICCF-2019 – International Conference on Computational Finance, A Coruña, Spain, July 8-12, 2019, as a satellite event to ICIAM 2019, Valencia, Spain, July 15-19, 2019. Matthias Ehrhardt is the Chair of the Scientific Committee and plenary speaker.

► A proposal by Michael Coulon, Carlos Vázquez and Tony Ware for a BIRS workshop in Banff (Alberta, Canada), on "New challenges in energy markets – data analytics, modelling and numerics" has been accepted, and is scheduled for Sept. 22-27, 2019.

Coordinators: Matthias Ehrhardt and E. Jan W. ter Maten,

Bergische Universität Wuppertal, Germany,
http://www-amna.math.uni-wuppertal.de/ecmi-sig-cf/
Mathematics for Big Data

Purpose

The availability of huge amounts of data is often considered as the fourth industrial revolution we are living right now. The increase in data accumulation allows us to tackle a wide range of social, economic, industrial and scientific challenges. But extracting meaningful knowledge from the available data is not a trivial task and represents a severe challenge for data analysts. Mathematics plays an important role in the existing algorithms for data processing through techniques of statistical learning, signal analysis, distributed optimization, compress sensing etc.

The amounts of data that are available and that are going to be available in near future call for significant efforts in mathematics. These efforts are needed to make the data useful. The main challenges we plan to consider within this SIG are, roughly speaking, in the area of mathematical optimization and statistics.

Opportunities

Minimization of a cost function, based on large amount of data is a typical problem in all big data areas – from smart agriculture, energy efficiency, computational biology, high tech industries based on simulations, material design, social networks analysis, challenge in policy decisions based on data, risk assessment in finance, security, natural disasters etc. The challenges in these areas, mathematically speaking are design of algorithms that will be able to process huge amounts of data within a reasonable time span and with computer power that is widely available today. Two important issues are distributed optimization and privacy issues. Several EU documents cite privacy of data as an important question that is to be resolved. On the other hand, distributed optimization allows us to employ optimization techniques in parallel, at several different computers placed in networks of different types. On another hand, extraction of meaningful information from data is one of the main tasks of Statistics. In presence of big data the most part of the usual techniques for statistical analysis can not easily been applied, since they are based on the simultaneous processing of the whole dataset. A big effort has been made during these years, mainly by computer scientists, to find fast and scalable procedures that have become popular in presence of distributed architectures (like e.g. the well known MapReduce paradigm). Unfortunately in many situations such procedures can not be applied to solve statistical problems in a distributed way, or they work under too much restrictive and thus unrealistic conditions. The deepening of the mathematical insight in this context may help to better understand the theoretical and applied power of the new algorithms and to extend them to more realistic cases. The deepening of the mathematical insight in this context may help to better understand the theoretical and applied power of the new algorithms and to extend them to more realistic cases. Sometimes data are “big” because of their high dimensionality and space-time structure (think e.g. to satellite images, signals registered by sensors or antennas, etc.). In such cases suitable mathematical techniques for dimensionality reduction are needed both for data visualization and for their numerical treatment. Functional Statistics, that is a field in which a lot of research is concentrating nowadays, may
help in facing this task. In other contexts data are considered “big” because of their complexity or heterogeneity (e.g. data extracted from social networks with text mining, mixed to socioeconomic data for marketing purposes; or data highly interrelated which may be represented by complex graphs, like atoms and bounds in a protein, relationships between users of a social network, etc.). Sentiment analysis and Topological Data Analysis are new statistical fields of research, still under development, which may help to tackle the problem of analyzing such data.

The aim of this Special Interest Group is to collect people working on the themes described above, coming both from academy and from “industry” (to be intended in a wide sense) to favor scientific collaboration and research, by organizing common activities.

Activities

A kickoff workshop has been held in Novi Sad (Serbia) on May 31 - June 1, 2017. The workshop was attended by over 70 participants, including many industrial delegates, and 19 talks have been presented as well as some posters. The workshop was closed by a round table where industrial delegates addressed the major challenges that their work and involvement with Big Data is posing to academy, both in terms of research and training of students.

A MSC-ITN-EID European project called BIGMATH has been submitted for evaluation in early January 2018. The project, coordinated by Università degli Studi di Milano, includes other 3 academic centres (IST Lisbon, TU-Eindhoven, University of Novi Sad) and 7 SMEs, and is aimed to recruit 7 PhD students who will work on Big Data related industrial mathematical problems spanning many fields of application.

Planned activities for 2018

A minisymposium of the SIG is planned to take place during the conference ECMI 2018, Budapest, June 18-22, 2018

For further information see https://sites.google.com/view/mathbigdata/home

Coordinators:
Natasa Krejic, University of Novi Sad
Alessandra Micheletti, Università degli Studi di Milano
Liquid Crystals, Elastomers and Biological Applications

Purpose

The ECMI Special Interest Group in Liquid Crystals, Elastomers and Biological Applications originated with discussions at British Liquid Crystal Society and ECMI meetings, and aims to focus the efforts of applied mathematicians in anisotropic fluids and solid mechanics. The SIG coordinators have since brought together researchers from various fields, and from around the world, by organising workshops and sessions at larger conferences. With new activity planned for the near future, particularly linking to other networks within Europe, the hope is to make the SIG increasingly international and interdisciplinary in the near future.

Opportunities

From a mathematical point of view, this research area encompasses the analysis of anisotropic materials through continuum mechanics, fluid dynamics, non-equilibrium physics and the analysis of ordinary and partial differential equations.

The intrinsic anisotropy of these materials leads to asymmetries in elasticity and stress which produce interesting couplings between elastic deformation, flow and order. Since these effects are key to a number of existing and burgeoning industries and scientific fields, such as liquid crystal displays, elastomeric materials and active fluids, there are multiple exciting and novel interdisciplinary opportunities for mathematicians in this field.

Activities

The Group is small at present but plans to expand through collaborations with the British and German Liquid Crystal Society and the UK Fluids Network. The SIG meetings to date include an Institute for Pure and Applied Mathematics (UCLA) workshop on “Partial Order: Mathematics, Analysis and Simulations” 25th-29th January 2016¹ a Centre de Recherches

¹http://www.ipam.ucla.edu/programs/workshops/partial-order-mathematics-simulations-and-applications/
Mathématiques (Montreal) two-week workshop on “Partial Order in Materials: Analysis, Simulations and Beyond” 21st -30th June 2016\(^2\) and a London Mathematical Society South West and South Wales Regional Workshop on Partially Ordered Materials, University of Bath 21st December 2016\(^3\) and a more recent international research workshop on "Partial Order in Materials: at the Triple Point of Mathematics, Physics and Applications" at the Banff International Research Station (https://www.birs.ca/events/2017/5-day-workshops/17w5059). New links have been formed from the SIG to groups around the world through a variety of methods, and links now exist to the University of Malaya (Malaysia), Nanyang Technological University (Singapore), the National Autonomous University of Mexico and the Centro de Investigación en Matemáticas, as well as the Indian Institute of Technology Delhi (India).

![Workshop participants from the SIG and Nanyang Technological University](image)

**Future activities**

We are pleased to announce a forthcoming research workshop on "**Nematics at the Meeting Point of Solid Mechanics and Fluid Dynamics: New Perspectives and Challenges**" at the University of Bath on the 28th and 29th June 2018. This meetings is funded by the EPSRC UK Fluids Network and is being organized under the auspices of the UK Fluids Special Interest Group on "Fluid dynamics of liquid crystalline materials" (https://fluids.ac.uk/sig/LiquidCrystals). The meeting brings together researchers working in nematic liquid crystals, their static and dynamic theories, optical modelling, numerical simulations and analogies between nematic theories and solid mechanics. This meeting will serve as a common platform to discuss recent exciting developments in nematic solitons, nematic microfluidics, the rich applications of nematics in confinement and nematics under flow along with powerful new computational techniques to explore the solution landscapes.

The seven confirmed speakers and their titles are given below.

1. Halim Kusumaatmaja (Durham, UK) Tentative title: Applications of energy landscape methods to problems in elasticity and liquid crystals.
3. Oliver Henrich (Strathclyde) Title: Mesoscopic Simulation of Flowing Topological Composite Materials.
4. Duvan Henao (PUC Chile) Title: Meeting points of cavitation and nematics.
5. Nigel Mottram (Strathclyde UK) Title: Trapped! - anisotropic fluids in confined geometries.
6. Ian Griffiths (University of Oxford) Title: Mathematical modelling for liquid crystal microfluidics.
7. Lei Zhang (Peking University) Title: Numerical Methods of Finding Transition States and its Applications in Materials.

This meeting is also partly supported by a Royal Society Newton Advanced Fellowship.

\(^2\)http://www.crm.umontreal.ca/2016/Order16/index_e.php

\(^3\)http://people.bath.ac.uk/jlpn20/lms2016.html
awarded to Apala Majumdar (University of Bath) and Lei Zhang (Peking University). The meeting is open to everybody and please send an expression of interest to Dr Apala Majumdar (a.majumdar@bath.ac.uk) if you are interested in attending. There is no registration fees and lunch & refreshments will be provided to all participants on both days. We look forward to welcoming you at Bath!

Coordinators: Apala Majumdar¹ and Nigel Mottram²

¹ University of Bath
² University of Strathclyde
Shape and Size in Medicine, Biotechnology and Materials Science

Purpose

Thanks to the development of information technologies, the last decade has seen a considerable growth of interest in the mathematical and statistical theory of shape and its application to many and diverse scientific areas. Often the diagnosis of a pathology, or the description of a biological process mainly depend on the shapes present in images of cells, organs, biological systems, etc. However, mathematical models that relate the main features of these shapes to the correct outcome of the diagnosis, or to the main kinetic parameters of a biological system are not yet present. In materials science, optimisation for quality control, texture description and prediction, …require methods of mathematical morphology.

Opportunities

From the mathematical point of view, shape analysis uses a variety of mathematical tools from differential geometry, geometric measure theory, stochastic geometry, etc. Quite recently, instruments from algebraic topology have been introduced for shape description, giving rise to a new field of research called Topological Data Analysis. As far as applications are concerned, the members of the SIG emphasize here topics which are relevant in medicine, biotechnology and materials science. We deal with direct and inverse problems. Among direct problems, spatio-temporal pattern formation deals with the analysis of how patterns are created and developed in biology, medicine and materials science. Modeling, numerical simulation and analyses of the corresponding systems are tasks of paramount importance for direct problems. Among inverse problems, we study various statistical techniques of shape analysis to measure in a quantitative way the random variability of objects; recent methods of image analysis include optical imaging of objects in turbid media, which can be used as a non-invasive technique for the detection of tumors in the body.

Activities

This year has seen the transition in the role of coordinator from Alessandra Micheletti (Università degli Studi di Milano) to Jesus Angulo (Ecole des Mines de Paris, Paristech) and Luis Bonilla (Universidad Carlos III de Madrid). Main activity so far:

- Workshop Physics and mechanics of random structures: from morphology to material properties in honor of Dominique Jeulin, Peninsula of Oléron, Atlantic Coast, France, June 17-23, 2018 (http://cmm.ensmp.fr/willot/PMRM/). The activities of the SIG Shape and Size in Medicine, Biotechnology and Materials
Science are to be presented and promoted during this Workshop since most of the Workshop topics are common to those of the SIG. Invited speakers in the Workshop include SIG members:

- Jesus Angulo, Mines ParisTech, France.
- Luis Bonilla, Universidad Carlos III de Madrid, Spain
- Vincenzo Capasso, Università degli Studi di Milano, Italy.

**Planned activities for 2019**

- New workshops or thematic minisymposia in international conferences are being planned and will be announced on the ECMI web pages.

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**Figure 1**: Comparison of experimentally measured strain and rotation fields of a dislocation in graphene to different theoretical reconstructions

**Figure 2**: A simulation of a mathematical model for angiogenesis

Coordinators: Jesus Angulo (Mines ParisTech, France), Luis L. Bonilla (Universidad Carlos III de Madrid, Spain)
Advancing the Design of Medical Stents

A number of events were organized over the past year, including the minisymposium “Applied mathematics in stent development” at ECMI 2016 in Santiago de Compostela and the three day workshop “Modelling and experiments in drug delivery systems” at University of Coimbra.

These events brought together in excess of 70 participants including mathematical modellers and experimentalists from several countries including the UK, Ireland, France, Italy, Portugal, Germany, Denmark, Iceland and Spain.

SIG Purpose

Coronary artery disease is a global problem and devising effective treatments is the subject of intense research activity throughout the world. Over the past decade, stents have emerged as one of the most popular treatments. Acting as a supporting scaffold, these small mesh devices are now routinely inserted into arteries where the blood flow has become dangerously restricted. Stents have evolved from bare metal scaffolds to polymer coated drug-delivery vehicles and, more recently, sophisticated fully biodegradable drug delivery configurations. Despite these advances, significant opportunities to improve on arterial stent design remain. In particular, research is focussed on the development of stents which accelerate the healing process to minimise thrombosis risk and which can be used in previously unserved patient groups and lesion types.

This SIG therefore consists of an international network of experts interested in stent research, and provides a platform to coordinate research efforts and help expedite the development of novel stent designs and technologies.
Modelling and experiments in drug delivery systems

The Modelling and experiments in drug delivery systems (MEDDS2016) workshop was held at the University of Coimbra in June 2016, under the auspices of the SIG. The workshop achieved its main goal of bringing mathematicians, biologists, physicians and engineers together in an open discussion environment. Whilst there were several talks on stents, the scope of the workshop was wider and included talks on drug delivery in general as well as several specific applications including transdermal delivery and intravitreal implants.

Applied mathematics in stent development

We organised the above titled minisymposium at the 19th European Conference on Mathematics for Industry (ECMI 2016) in Spain. There were five contributed talks from members of the SIG. The talks covered the development of innovative models to help industry optimise and improve stent design, to identify the key parameters governing the behaviour of the system, to simulate the flow of plasma around complex stent geometries, to identify the drug release mechanism, and to help decrease the number of experimental studies, thereby saving time and money. The minisymposium was attended by researchers with expertise in continuum mechanics, physiological flow modelling, structural and soft tissue mechanics, numerical analysis, mathematical biology and multi-objective optimisation, to name but a few. The talks included:

- **The role of mathematics in stent development**, Dr Sean McGinty, University of Glasgow (Scotland).
- **Optimizing the performance of drug-eluting stents: simulations and experiments**, Prof Abdul Barakat, Ecole Polytechnique (France).
- **Mathematical models of drug release from polymer-free drug-eluting stents**, Dr Tuoi Vo, University of Limerick (Ireland).
- **Variable porosity coatings as a means of controlling drug release from stents**, Dr Giuseppe Pontrelli, IAC-CNIR, Rome (Italy).
- **Numerical simulation of drug transport in arterial wall under healthy and atherosclerotic conditions**, Javier Escuer, University of Zaragoza (Spain).

SIG Inaugural Committee Meeting

ECMI 2016 also provided the opportunity for us to hold our first SIG Committee meeting, attended by members of the SIG Committee as well as ECMI president Dietmar Hoemberg. It was decided that the SIG seed money would be used to fund a workshop with an Industrial presence (see below). Among the matters raised at the meeting included the possibility of widening the
scope of the SIG in the medium-term to include medical implants and/or drug delivery devices more generally. The idea of submitting a proposal for an EU PhD training network was discussed as well as the possibility of writing a book related to the themes of the SIG which could also act as a teaching resource.

Forthcoming Activities

The SIG intends to submit a minisymposium proposal for the ECMI 2018 conference and additionally plans to use the SIG seed money to partially fund a 3 day workshop in Autumn 2018 in Glasgow, on the theme of “Modelling and experiments in drug delivery systems”. A full day of the workshop will be designated as an Industrial workshop, and another full day dedicated to stents research. The attendance of companies, clinicians and experimentalists will only serve to enhance collaboration in this multi-disciplinary area. Those interested in attending should contact Sean McGinty (sean.mcginty@glasgow.ac.uk) or Tuoi Vo (tuoi.vo@ul.ie).

Coordinator: Sean McGinty

University of Glasgow
Net Campus for Modeling Education and Industrial Mathematics

The ECMI Special Interest Group Net Campus for Modeling Education and Industrial Mathematics was launched in 2017 following initiatives taken by ECMI’s Educational Committee. The aim of the SIG is to coordinate the already ongoing activities at the various ECMI centers in the field of online and digital education and extend them towards joint ECMI online courses.

Purpose

The ECMI educational committee has taken virtual education and web-supported solutions as one of its target areas to complement the other strategic areas like ECMI curriculum development, modeling weeks, mobility of students & staff etc.

The cutting edge knowledge in industrial mathematics is dispersed at small nodes of expertise. Online environments are a viable media to access this knowledge and support innovative processes, training and educational needs, to facilitate distributed consultation processes, etc. The evolution from textbook to interactive cross media environments means a new learning paradigm. Advantages include easy access and portability, flexible updates, dynamic edition, multi-/hypermedia tools from search facilities, quiz–structures to animations, interactive exercises, remote lectures and videoconference etc.

We envisage to build a European digital environment and web–portal for applied and industrial mathematics. More immediate goal is to share information and experience, describe examples of web based courses in applied mathematics and technologies for web publication of interactive documents. Such environment are suitable for students in applied mathematics and engineering programs in advanced BS and MS level as well as for persons who are already in their working life and are looking for continuing education and professional development. The courses should be based on customized content for a special applications area.

Activities

The kick-off meeting initiating this SIG has been held at the university in Koblenz, Germany (March 23–24, 2017). Here, the structure and participants of a first introductory online course on mathematical
modeling were discussed.

At the ECMI 2018 conference in Budapest (June 18–22, 2018) we will organize a minisymposium dedicated to online educational issues.

**Online Course Description**

In October 2017, the “ECMI Modeling Course” was hosted on the Moodle platform at Lappeenranta University. Coordinated by the University in Koblenz, six introductory real-world problems were selected and preprocessed for undergraduate student’s use. In summary, 30 students from all partner universities participated in this first round. In detail, the problems included the following topics (posing partner in parenthesis):

1. Indoor mobile phone positioning using access point signals (Tampere, Finland),
2. Opinion dynamics on social network graphs (Verona, Italy),
3. Stratospheric beanstalk modeling (St. Petersburg, Russia),
4. Pursuing the sun (Koblenz, Germany),
5. Ecological forest growth modeling (Lappeenranta, Finland),
6. Indoor shortest path problems (Coimbra, Portugal).

![Figure 1: Indoor positioning (Problem 1). True (olive) versus calculated path (red) of a mobile phone user in a building (blue). Axes are only for scale.](image1)

![Figure 2: Pursuing the sun (Problem 2). Path on the earth’s surface when following the sun using different integration methods (blue and red). Axes scaled to a normalized earth radius of 1.](image2)

Coordinators: Dietmar Hömberg\(^1\), Thomas Götz\(^2\), Robert Rockenfeller\(^2\) and Matti Heiliö\(^3\)

\(^1\) Weierstrass Institute Berlin, Germany
\(^2\) University Koblenz-Landau, Germany
\(^3\) Technical University Lappeenranta, Finland
About ECMI

Mission

Mathematics, as the universal language of the sciences, plays a decisive role in technology, economics and the life sciences. European industry is increasingly dependent on mathematical expertise in both research and development to maintain its position as a world leader for high technology and to comply with the EU 2020 agenda for smart, sustainable and inclusive growth. ECMI initiatives in response to these needs may be summarized as follows:

- ECMI advocates the use of mathematical modelling, simulation, and optimization in industry
- ECMI stimulates the education of young scientists and engineers to meet the growing demands of industry
- ECMI promotes European collaboration, interaction and exchange within academia and industry

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ECMI Mission

Mathematics, as the universal language of the sciences, plays a decisive role in technology, economics and the life sciences. European industry is increasingly dependent on mathematical expertise in both research and development to maintain its position as a world leader for high technology and to comply with the EU 2020 agenda for smart, sustainable and inclusive growth. ECMI initiatives in response to these needs may be summarized as follows:

- ECMI advocates the use of mathematical modelling, simulation, and optimization in industry
- ECMI stimulates the education of young scientists and engineers to meet the growing demands of industry
- ECMI promotes European collaboration, interaction and exchange within academia and industry

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