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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  - Advancing the Design of Medical Stents
  - Net Campus for Modelling Education and Industrial Mathematics
Dear Colleagues!

As ECMI is heading for the end of it’s fourth decade of existence, it continues to thrive and expand its activities. Along with the long-running and widely popular modelling weeks – which now come in a Summer and Winter edition – we also have established a scheme for Special Interest Groups. These SIGs focus on a whole range of areas in the applied and industrial mathematics universe. SIGs are actively supported by ECMI in particular through (co-)funding of SIG related events, such as travel support for speakers or junior research members. If you are interested in setting up an SIG, please contact the Research and Innovation Committee chairman, Wil Schilders. You will need to write a short proposal for the SIG (and subsequently, for the events you would like to receive support for), and, once approved, you are ready to roll. SIG coordinators provide a yearly report of their activities, which are published in the ECMI annual report (as in this issue).

Last year was an even year, i.e. a year of the bi-annual ECMI conference, which took place in Budapest, and was widely successful (more on this in the section on “Activities and Initiatives” in this issue). The year 2019 is an ICIAM year, and we as ECMI are showing our flag – for example through an ECMI booth and dedicated mini-symposia. We hope to attract a lot of attention, and that all our members will spread the word!

Andreas Münch, University of Oxford, June 2019
Dear colleagues,

The year 2018 has been a year of growth and many activities in European Industrial Mathematics. The ECMI conference that took place in Budapest in June was a very successful event, with more than 350 participants from around 40 countries. I would like to thank Péter Simon and his team for organising such a wonderful and stimulating conference. We are now very much looking forward to welcoming you all to the 21st ECMI conference, which will take place in Limerick, Ireland, from 22-26 June 2020. I am sure it will be an excellent memorable event and a great opportunity to strengthen collaborations between researchers and companies, promoting innovation and enhancing industry-academia relations at the international level.

The annual ECMI modelling week for students, held in July in Novi Sad, was also a success, bringing together masters students and mentors from a variety of ECMI member countries to collaborate in groups on industrial problems. This year, we also launched a new Special Interest Group on Modelling, Simulation and Optimization in Electrical Engineering and no less than 10 Study Groups with Industry took place in different countries around Europe, the latest one being ESGI 146 in December, in Cyprus.

As we reflect on the year that has passed, we ponder on what we can do better to continue to make a difference in our community. Knowledge has become the main wealth of nations, companies and people. Hence investing in research, innovation and education is now the key-leverage for competitiveness and prosperity in Europe. We believe that mathematics is an essential factor in the industrial creation of value and a driving force for innovations, providing a logically coherent framework to industry and a universal language for the analysis, modelling, simulation, optimisation, and control of industrial processes.
It is worth mentioning that recently H2020 granted the project proposal BIGMATH presented by the ECMI Special Interest Group “Mathematics for Big Data”. Within this project, 4 academic institutions and 7 companies from different European countries will collaborate to train a group of 7 PhD students with strong theoretical and practical skills, needed to tackle relevant industrial Big Data challenges. This is clearly a good example of an ECMI success story: it promotes the use of mathematics in industry, contributes to educate young industrial mathematicians and operates at a European level.

I highlight the need for close collaboration between academia and industry in order to bring out innovation ecosystems. And, for sure, ECMI provides the perfect environment for developing such collaborations. Please take a look to this edition of our Annual Report where you can find a snapshot of our activities. You can always follow the latest developments at the ECMI blog.

I would like to take the opportunity to express my sincere gratitude to Jan ter Maten who served ECMI as Secretary and Treasurer for many years. His dedication and hard work were truly remarkable and are still a great source of inspiration for all of us. Finally, I cannot finish without my heartfelt thanks our outgoing President Dietmar Hömberg. Dietmar provided ECMI with direction and leadership and handled all issues with diplomacy and good humour. As the new president, I hope to be able to continue to rely on his wisdom and good judgement.

Adérito Araújo

University of Coimbra, May 2019
Activities and Initiatives
The 20th European Conference on Mathematics for Industry, ECMI 2018 was held in Budapest from 18-22 June 2018. Hungary is well-known for its outstanding achievements in pure mathematics, but much less known for its contributions to applied mathematics, in spite of the works of outstanding scientists like, Gyula Farkas, Theodore von Kármán, John von Neumann or Rudolf E. Kalman. Therefore it was the privilege of the Hungarian mathematics community to have the opportunity to reinforce the contacts with the major European network promoting industrial mathematics, by bringing together more than 350 researchers for intellectual interaction for 5 days.

Goals and topics

The European Consortium for Mathematics in Industry (ECMI) organized its first international conference in Oberwolfach, in 1983. This was followed by a series of conferences, a persistent objective of which has been to galvanize interaction between academy and industry, leading to innovations in both fields.
Factories, Brain Research or Precision Agriculture, supported by the EU and the National Research, Development and Innovation Office.

Organization and numbers

The conference was jointly organized by the János Bolyai Mathematical Society, the Institute of Mathematics at Eötvös Loránd University, and the Institute for Computer Science and Control of the Hungarian Academy of Sciences (MTA SZTAKI). The newly appointed Minister of Innovation and Technology, László Palkovics was kind enough to patronize our conference. The statistics of the conference were more than satisfactory. In addition to the nine plenary talks, given by world class researchers, we had 50 minisymposia, and 45 contributed talks and poster presentations, running in 7 parallel sessions. Altogether there were more than 350 participants, from around 40 countries. More than 50 participants were students.

Program

The plenary talks covered several major areas of applied and industrial mathematics, such as network theory, numerical methods of PDEs, mathematics of tomography, mechanical models, traffic management, control theory, cancer research, environmental modelling. The plenary speakers were: Paola Goatin, INRIA Sophia Antipolis - Team ACUMES, France, Stefan Kurz, TU Darmstadt and Robert Bosch GmbH, Germany, Knut-Andreas Lie, SINTEF Digital, Mathematics & Cybernetics, Oslo, Norway, László Lovász, Hungarian Academy of Sciences, Hungary, Christophe Prud'homme, University of Strasbourg and Cemosis, France, Samuli Siltanen, University of Helsinki, Finland, Gábor Stépán, Budapest University of Technology and Economics, Hungary, Andrew Stuart, CalTech, USA, Anna Marciniak-Czochra, University of Heidelberg, Germany, delivering the Alan Tayler Memorial Lecture. The plenary talk given by László Lovász, President of the Hungarian Academy of Sciences, has been recorded, processed and made available by the eLearning Department of MTA SZTAKI, at the address: http://www.bolyai.hu/ECMI2018_video.html

According to the tradition of ECMI conferences, the winner of the Anile prize, honouring Professor Angelo Marcello Anile, (1948-2007) of the University of Catania, was announced at the opening ceremony of the conference. The prize is given to a young researcher for an excellent PhD thesis in industrial mathematics. The Anile prize, in

Group photo
2018, was awarded to Peter Gangl, Johannes Kepler Universität Linz. The Hansjörg Wacker Memorial Prize, established in memory of ECMI founding member Hansjörg Wacker, (1939-1991), who was Professor at the Johannes Kepler University, Linz, is awarded for the best mathematical dissertation at the Masters level on an industrial project. The Hansjörg Wacker Memorial Prize, in 2018, was awarded to Edvin Ablad, Chalmers University.

The conference venue was the Danubius Hotel Hélia. As part of the social program, an ECMI reception was held in Tuesday evening to create an opportunity for ECMI members to meet each other. The conference gala dinner was held in a Danube river cruise on Europa boat. During this event, Hilary Ockendon and István Faragó, who initiated the ECMI membership of Hungary, were elected to be Honorary Members of ECMI.

**Acknowledgement**

The Organizers express their deepest gratitude to everybody involved in the success of this meeting, the plenary speakers, the members of the Scientific Committee, the organizers of the minisymposia, the contributing authors and all the participants of the conference.

It is our pleasure to acknowledge the financial support of Graphisoft, Secudit, Morgan Stanley, the Hungarian Academy of Sciences and the EPIC Centre of MTA SZTAKI, providing the financial basis for the participation of many young researchers.

Péter L Simon, István Faragó and László Gerencsér

Eötvös Loránd University and MTA SZTAKI
MIMESIS – Mathematics and materials science for steel production and manufacturing

The doctoral programme MIMESIS, with its research funding of € 2.1 million, encourages mobility on various levels. Within the European Industrial Doctorate (EID) programme in the Marie Skłodowska-Curie actions of the EU, the participating partner organisations recruit early stage researchers (ESRs), who have lived for a maximum of one year in the last three in the country in which the partner is located. The ESRs spend at least 18 months with an industry partner, thereby encouraging inter-sectoral mobility. Finally, the project has a clear interdisciplinary makeup: four PhD students are from materials science and four from mathematics. The Finnish University of Oulu (UO) and the Weierstrass Institute in Berlin (WIAS) are the scientific members of the consortium, whilst companies in Norway and Finland are the industry partners.

Introduction

Almost all manufacturing sectors, from construction through transport to consumer goods, are largely based on the utilisation of steels. Steel products often compete favourably with alternative material solutions in cost efficiency and life cycle analyses. The last fifteen years have seen the development of ever more refined high-strength and multiphase steels with purpose designed chemical compositions allowing for significant weight reduction, e.g., in automotive industry. The production of these modern steel grades needs a precise process control, since there is only a narrow process window available in which the desired physical properties are defined. In combination with component walls getting thinner and thinner these new steels make also new demands on a more precise process control in metal manufacturing processes, such as welding and hardening.
Improved and optimised process control requires quantitative mathematical modelling, simulation and optimisation of the complex thermal cycles and thermal gradients experienced by the processed material. Such models require an understanding of the behaviour of the materials from a materials science and phase transformations perspective. Unfortunately, it is almost impossible for companies to find graduates combining deep knowledge in materials science with expertise in mathematical modelling.

To fill this gap, five partners from steel production (Outokumpu, SSAB) and steel manufacturing (EFD Induction), from materials science (UO) and applied mathematics (WIAS) established the European Industrial Doctorate program on “Mathematics and Materials Science for Steel Production and Manufacturing (MIMESIS)”, where eight PhD projects are jointly carried out, providing a unique interdisciplinary and inter-sectorial training opportunity.

The research is focussed on three major topics along the process chain for steel production and manufacturing. Two theses are related to secondary metallurgy in the ladle considering computational fluid dynamics models of ladle treatments and optimal control of ladle stirring (WPs 5&6) and two theses are concerned with phase transformations during steel production (WPs 4&8). Two theses concern the induction hardening process: one is on the hardening of helical and bevel gears by an optimised single or multi-frequency approach and the other is a novel idea about the hardening of the inner surface of pipes (WPs 2&3). One thesis studies a prototype set-up for inductive pre- and post-heating in the thermal cutting of steel plates and one is related to high-frequency welding of steel tubes (WPs 1&7). The latter
will be discussed in more detail in the following sections.

A specific highlight of the programme were customised three-month courses on steelmaking, physical simulation and testing of steels in Oulu and on numerical simulation and optimisation in Berlin. Additionally, the ESRs also had tailored on-site industrial trainings offered by three industrial partners. All the students have been exposed to two different industrial partners. They work on up-to-date research topics of high industrial relevance on the interface of materials science, applied mathematics and industrial practice.

**Tube welding – a case study**

High-frequency induction welding is widely used, especially in the production of superior quality oil and gas pipes and structural tubes. A steel strip is cold-formed into a tubular shape in a continuous roll forming mill. The strip edges are electromagnetically heated and joined mechanically by pushing the strip edges against each other to form the longitudinally welded tube.

The welded joint as seen in the transverse cross-section of a welded tube, is a very narrow zone compared to the tube diameter. The strip edges are heated to almost melting temperature and are pushed against each other in the viscoplastic state to form the welded joint where crystallographic texture and microstructural changes appear.

The electromagnetic heating of the tube is analogous to transformer theory. The coil is the primary current source, the strip is where the current is induced and the impeder acts as a magnetic core. The entire setup, coil current and frequency determine the amount of the induced current in the tube.

![Figure 3.2. High Frequency induction welding of a steel tube.](image)

High-frequency alternating current is supplied to the induction coil. This induces eddy currents in the strip under the coil. The induced current can follow the principal paths indicated in the figure above to complete the circuit. Along the strip edges, it can flow downstream from the coil towards the welding point or away from the coil in the upstream direction. At any strip cross-section, the current can follow a path either along the outer circumference or the inner circumference. The goal of high-frequency induction welding is to maximise the current density in the strip edge downstream, towards the welding point.

The relative positioning of the strip, induction coil and impeder is very important to obtain an efficient heating process. The geometric shape of the opening between the strip edges is usually a Vee shape. Sometimes it is distorted by spring-back due to the mechanical forming of the strip. This
also affects the current distribution. Further important process parameters are the coil current and welder frequency. For better understanding of the complex interactions between the above parameters, numerical simulation is an indispensable tool. In [1] we present the first comprehensive simulation approach for high-frequency induction welding in 3D. Its main novelties are a new analytic expression for the space-dependent velocity of tubes accounting for arbitrary Vee-angle and spring-back and a stabilisation strategy, which allows us to consider realistic welding-line speeds.

In [1] we present the first comprehensive simulation approach for high-frequency induction welding in 3D. Its main novelties are a new analytic expression for the space-dependent velocity of tubes accounting for arbitrary Vee-angle and spring-back and a stabilisation strategy, which allows us to consider realistic welding-line speeds.

The heat equation is discretised by linear nodal finite elements. To account for high speeds somewhere in the range of 40m/min to 200 m/min the Streamline Upwind Petrov Galerkin (SUPG) method is utilised. The discretisation of Maxwell’s equations is done with Nédélec elements of lowest order. The magnetisation depends both on the temperature and the magnetic field. For fixed temperature this nonlinearity is resolved numerically based on an averaging approach [2]. The coupled system is iteratively decoupled and solved using a fixed point iteration.

Simulation results

The first figure is a simulation result of current density distribution in the strip edge. It shows current concentration both in the downstream and upstream directions with a maximum close to the weld point.

Examples of temperature distribution in the welded strip are shown in the last figure for two different Vee-openings and a springback distorted opening. The strip edges are heated to very high temperatures because of Joule heating from eddy current concentration. The velocity function incorporates the mechanical forming of the strip into a tube in addition to the welding-line velocity.
Conclusions

A three-dimensional model has been developed for high-frequency induction welding. It is a non-linearly coupled system of Maxwell’s electromagnetic equation and the heat equation. The results show a temperature distribution in the strip edges that develops as expected from previous studies and visual observations of the process. The strip length also decides the amount of induced current that goes to the welding point. A wider Vee-angle results in a wider heat affected zone. Increasing the frequency reduces the width of the heat affected zone. It is also shown that for the thinner wall the hour glass shape of heat affected zone is less pronounced. These results are in line with what is expected. This new three-dimensional simulation tool will provide a basis for an optimisation of the design of the welder, especially with respect to the dimensioning of induction coil, impeder and the configuration of these relative to the steel strip. Future work will include the study of the mechanics of the material squeeze-out when the strip edges are joined together after heating.

Prerana Das², Dietmar Hömberg¹
¹ Weierstrass Institute, Berlin, Germany
² EFD Induction, Skien, Norway

References


4

Featured People
Interview: Peter Gangl

Peter Gangl is a university assistant at Graz University of Technology. He completed his bachelor, master and PhD studies at Johannes Kepler University Linz. For his PhD thesis he received prizes from the Austrian Mathematical Society, the Society for Industrial and Applied Mathematics (SIAM) and ECMI.

Tell us a little bit about your background: what interests and training led to where you are now?

I studied Mathematics in Linz, Austria. My masters was called Industrial Mathematics, so already there is some connection to Industrial Mathematics and to the ECMI. Also in Linz ECMI is very well established, so they are involved in various organisations. As a student I had the opportunity to attend the modelling weeks, so I got to know the organisation of ECMI early.

In addition I was lucky enough to get a PhD topic which was applied, and which was interesting from a mathematical point of view and from an application point of view. It was a collaboration with electrical engineers from University of Linz. The topic was the optimization of electrical machines, and that is what most of my Phd revolved around and what I am still working on.

Your PhD led to the Anile prize. Do you want to tell us what your PhD entailed, and what kinds of applications it has to industrial mathematics?

The topic was the optimisation of electrical machines, in particular the shape and topology optimization of electrical machines. So the task was to find out how they should be shaped such that the arising magnetic fields are optimal in some sense such that the behaviour of the machine, in the end is as good as possible.

So I started mathematical analysis to make a shape sensitivity analysis, and topological sensitivity analysis, and spent a lot of time just working in my mathematical function spaces and finally derived some formulas. During this time I developed a simulation tool for electrical machines and also incorporated the sensitivities I computed analytically into this program. This way, it
was possible to run optimization algorithms and finally obtain optimized designs for some model problems. I do not want to guarantee it's the best possible design in all different respects because there are always a lot of different requirements on the final design which you want to produce. I was just considering electromagnetic properties and, for instance, I did not care about mechanical stability, which of course is an important topic as well.

So now you are based at TU Graz. How did that transition happen? After my PhD I was in Linz for six months as a postdoc. This position (in Graz) opened up. It is quite a nice position as it is a university position. I have quite a lot of teaching duties, which is good and bad, but primarily it is good as it is experience that I wanted to have. I teach my own courses. Just this semester I am teaching a special lecture on my research topic, which is quite interesting and quite exciting for me. On the other hand, I still have some time to do my research around the topic of the simulation and optimization of electrical machines, but taking into account other aspects, like for example uncertainty quantification, which is something I'm about to start soon.

So now that you are teaching is there any advice you would give to students or young mathematicians who want to work in or with industry? If they want to get involved with industry early during their studies, there are more possibilities to get real world projects than they might think, because many professors collaborate with industry and so if you are interested in doing a project - a bachelors or masters thesis - on an applied topic in cooperation with some company, then you can maybe just approach your professors and ask them if they have something like this.

My first contact with industrial mathematics was the ECMI Modelling week, which I attended as a student, and which was a very good experience.

Maybe also think about an internship during the summer vacation. I also did that when I was a student, and these were also valuable insights for me.

Interviewed by Christian Goodbrake
Mathematical Institute
University of Oxford
Interview: Otmar Scherzer

Otmar Scherzer is Professor for Computational Science at the Faculty of Mathematics at the University of Vienna, Austria and group leader at the Radon Institute of Computational and Applied Mathematics (RICAM), in Linz, Austria. He is one of the pioneers in the fields of inverse problems and regularization theory. We interview him on the occasion of his 2018 EAIP award.

How did you get involved in working in the field of applied mathematics?
As a student I was enrolled in two bachelor programs at the University of Linz: technical mathematics and computer science. It didn’t take a lot of time to realize that mathematics is my field of interest and to quit computer science. The possibility to formulate new mathematical problems and the opportunity to work on problems coming from physics, engineering, and in particular from medicine, fascinated me.

You have been an active researcher for more than 30 years. How has the research in the field evolved in this period?
Especially in the field of industrial mathematics there has been a dramatic change in the mathematical work due to computers. In my early career asymptotic analysis and mathematical modeling for simplifying reality where the dominating pillars. Computer simulations became more and more important and much more detailed models could be simulated. So numerical analysis and computer simulations based on detailed physical and engineering models became strong research components in addition. Now there comes a new trend from Computer Science with machine learning.

What kind of problems are you dealing with currently?
I am mainly working on inverse problems, imaging and image analysis. In both settings, we have to reconstruct an object (position, shape, properties) from measurement data, which are indirect (not measuring the object of interest directly), incomplete and noisy. At the Computational Science Center of the Faculty of Mathematics at the University of Vienna, we are working on mathematical analysis and numerical algorithms of variational methods and modeling and simulation of emerging tomographic techniques.

And how do they are connected to industrial applications? Can you describe some of the ongoing projects?
Our main research grant is the Special 22 Collaborate and Cooperate Annual Report 2018 Featured People
Research Program “Tomography across the scales” funded by the Austrian Science Fund. It consists of six sub-projects at five universities and one research institute. We are dealing with problems of super resolution microscopy, tomography and astronomy. This project brings together mathematicians, physicists and biologists. We are also collaborating quite successfully with two industrial partners on topics related to imaging. The industry transfer projects and basic research projects share interdisciplinary collaboration. However at the end, the goals are complementing each other: The basic research topics are knowledge gain driven while the industrial research is product orientated.

Your research contributions have been recently awarded by the Eurasian Association on Inverse Problems (EAIP). Can you tell us about this prize?
The EAIP was founded in 2013 and is a non-governmental organization coordinating research groups working on inverse problems in Europe and Asia. The award is given every two years at the International Conference on Inverse Problems: Modelling and Simulation. The members of the Committee and the previously awarded researchers V. Vasin, B. Hofmann, J. Boman and S. I. Kabanikhin justify the importance of this prize. The prize, in particular honors researchers, which are conducting joint research project with European and Asian researchers.

It was my great pleasure to share the 2018 award with V. G. Romanov and I am really grateful to all my group members and international collaborators. This award is a strong motivation for being an active part in the inverse problems research community.

Tells us about your involvement in ECMI.
Since 2011 I have been the contact person of the Vienna node and I am a series editor of ECMI in Springer. The former members of CSC Daniel Leitner and Leonidas Mindrinos were Council members and now Gwenael Mercier represents our group in ECMI.

Can you highlight some of the achievements of the Austrian ECMI nodes?
Since the early years of ECMI, Austria was an active member. Johannes Kepler University was one of the founding nodes (1987) and two years later the 4th ECMI Conference took place in Strobl. Hansjörg Wacker (1939-1991) was one of ECMI founding members and also President. Then, the 5th Modeling Week was held in Linz. Heinz Engl, now Rector of the University of Vienna, was also President of ECMI (1994-1996). More recently, the 149th European study group with industry was held in Innsbruck with success.

Do you think that the gap between academia and industry has been shortened over the last years?
Of course, now there are several funding opportunities for collaborations between Universities and Industry on many levels. ECMI and similar organizations have helped a lot to open these funding opportunities, and it provides an infrastructure for such.

How do you see the field progressing in the following years?
Industrial Mathematics or Mathematical Imaging? Both fields are enormously emerging due to breakthrough research on the one hand and social interest on the other. In Industry new challenges come from big data and the expected social changes - There is an interesting road map article of Villani on expected social changes due to machine learning. In my field of mathematical imaging I expect that ultra-high resolution microscopy will revolutionize Biology and Medicine, and it will have even more commercial aspects in the future, and thus also an industrial mathematics component.

Interviewed by Dr. Leonidas Mindrinos
Johann Radon Institute, Linz, Austria
Projects and Case Studies
Modelling sample charging in SEM

Scanning Electron Microscope (SEM) is the main research instrument for investigating the structure of micro- and nanometer sized objects. Normally the sample is coated with a thin film of gold. However in many applications involving insulators, metallic coating is either not possible or not desirable. With such samples the SEM images often become distorted and difficult to interpret due to charging. Similar problems are encountered in solid-state particle detectors and e-beam lithography. Mathematical modelling of this charging process is essential for choosing an optimal imaging regime and designing new SEM’s [1, 2].

Almost universally interaction between electron beams and insulating targets is modelled with semi-classical Monte-Carlo (MC) methods, where the classical trajectories of many individual particles subject to various quantum-mechanical scattering processes are traced in time in an attempt to estimate the resulting charge distributions and the secondary electron yield [3]. Since available models tend to become computationally expensive, unreliable, and difficult to interpret, especially at lower electron energies, a major SEM producer (FEI Company/Thermo Fisher Scientific) has posed a problem of either accelerating the existing codes or finding a better solution [4].

As a faster alternative to discrete MC simulations we have developed a finite-element code implementing a continuous approach to this problem via a coupled system of Drift-Diffusion-Reaction equations [1]. To make reliable predictions the code was calibrated against experimental data [2]. Our methodology has been applied in the analysis of the new particle detector [5].

The work on this problem started at the Physics With Industry workshop in 2011, continued as a PhD project of one of the authors (BR) and expanded into a successful collaboration between the Numerical Analysis group and the Department of Imaging Physics at TU Delft.

Problem description

In a typical SEM a beam of electrons accelerated to a specific energy, which may range from 100 eV to 20 keV, is focused into a spot of just a few nanometres across the sample surface. A complicated magneto-electric system controls the beam position and lets it scan the sample in an orderly fashion. Normally, insulators do not have any “free” electrons, i.e. such that there is enough energy to be able to move through the material whenever an electric potential is applied. However, the highly energetic primary electrons (PE) of the SEM beam may ionize the atoms of the insulator.
so that the secondary electrons (SE) have enough energy to become virtually free. One PE can create several SEs per collision, some of which will be energetic enough to ionize other atoms, etc. Eventually, a few of these SEs will escape the sample and reach the detector. As the beam moves across the sample the number of detected SEs is presented as the pixel intensity of the SEM image – the brighter the pixel, the more SEs have been emitted by the material at that beam location.

However, not all excited SEs will leave the sample or recombine to form neutral atoms again. Many SEs will become "trapped" between the two states neither being able to move freely nor recombining. These "trapped" electrons create a long lasting spatial charge inside and on the surface of insulators. The field of trapped charges may be significant enough to completely reflect the incoming PE's preventing them from reaching the sample surface. Even a relatively weak charging shows as blurring of SEM images. Hence, the goal of mathematical modelling is to be able to predict the rate and extent of charging of a given sample under various illumination conditions, i.e., PE energy, beam current, type of substrate and ground contact, etc.

Semi-classical Monte-Carlo (MC) simulations have become the industry standard in the analysis of high-energy particle interactions. MC simulations are highly appealing due to the intuitively clear interaction picture they afford. Yet, this approach is less reliable and computationally expensive when it comes to the interaction of relatively low-energy (below 1 keV) particles with dense materials, especially in the presence of memory effects, such as the aforementioned particle trapping.

An alternative approach applicable at lower electron energies, typical for solid-state electronics, is the Drift-Diffusion-Reaction (DDR) approximation of the Boltzmann Transport Equation (BTE).

“Our idea was to augment the DDR equations with a source function that provides a continuous effective description of a single PE impact and to modify the boundary conditions to include the possibility of SE's escaping through the sample-vacuum interface.”

However, the standard DDR method does not provide an adequate description for the PE injection process and for the subsequent rapid ionization. Our idea was to augment the DDR equations with a source function that provides a continuous effective description of a single PE impact and to modify the boundary conditions to include the possibility of SE's escaping through the sample-vacuum interface.

Modelling and calibration

Numerical solution of DDR-type problems is no longer considered a difficult problem. Previously, the only computational challenges are realistic three-dimensional targets and sufficiently long time scales. An efficient FEM solver has been implemented in Comsol Multiphysics package with
Figure 1: PE penetration depth in alumina as a function of energy. Tuned values and six alternative analytical predictions.

execution times in the order of several minutes for a single PE impact. This allowed for many repetitive runs of the code that were needed to investigate alternative models of effective source functions.

To model the sample-vacuum interface a nonlinear boundary condition was introduced that took into account the possibility for a portion of SE’s to be re-injected into the sample whenever the accumulated positive charge was greater than the expected energy of emitted electrons. The boundary condition was formulated in such a way that the re-injection took place non-uniformly across the sample surface in accordance with the computed attractive electrostatic force.

The most challenging part of the project was the calibration of our model against experimental data. On the one hand, both the source model and the new boundary condition contained enough parameters to be able to tune the output of the model – the so-called SE yield (number of detected SE’s per one PE) – to any experimental data. On the other hand, per case tuning of parameters would, obviously, limit the predictive power of the model. Careful analysis of model assumptions revealed that most of the parameters could be fixed a priori based on the beam energy and bulk material parameters such as density, atomic number, ionization energy, etc. One important parameter of the source function, namely, the SE cloud generation time, has been fixed at a value that produced physically plausible transient SE emission patterns as qualitatively described in the literature.

while fixing another parameter of the source function – the PE penetration depth as a function of energy – we had initially attempted to choose between six alternative analytical expressions, finding out that one of these formulas is perfectly suitable for PE energies above 2 keV. However, below this threshold the penetration depths appear to be material-dependent and thus have to be

“The most challenging part of the project was the calibration of our model against experimental data.”
fitted against the standard yield data – Figure 1.

The remaining free calibration parameter of the model is the effective surface recombination velocity at the sample-vacuum interface, which one expects to be material-dependent but independent of the PE energy. By tuning this parameter and the PE penetration depths below 2 keV we were able to reproduce the experimental yield curves of two common insulators (silica and alumina) better than any other model, including MC simulations. Moreover, the difference in yields for different types of alumina samples (polished and unpolished) was faithfully reproduced by a lower recombination velocity in the unpolished case, as expected, without re-tuning the PE penetration depths, since those should not depend on the surface quality – Figure 2.

Having calibrated the code against the uncharged yield data we analyzed the effects caused by a prolonged irradiation of samples. As Figure 3 shows, this leads to the build-up of trapped charges, mostly on the sample surface, around the beam injection point.

![Figure 3: Charge build-up (C/cm³) on the surface of an isolated alumina sample irradiated by a focused 5 keV 100 pA stationary beam.](image)

**Charging dynamics**

Further verification of the code consisted of reproducing some known experimental observations and quantitative one-dimensional predictions obtained previously with a different method.

For example, it is known that the yield, which initially differs from unity (see the yield for an uncharged sample in Figure 2), collapses to unity (one SE per one PE) if the sample is irradiated for a longer time – Figure 4. Also, significant electrical potentials, both negative and positive, have been experimentally observed at the sample surface as confirmed by Figure 5.

![Figure 4: Yield dynamics for an alumina sample at different PE energies.](image)

![Figure 5: Electric potential as a function of time at the beam entry point for an alumina sample at different PE energies.](image)

Our FEM code allows studying realistic composite samples and the actual SEM scanning process, where the injection point of a focused beam moves along the sample surface. In particular, we have observed that the charging and, therefore, the yield may depend on the scanning direction as illustrated in Figure 6.
Figure 6: Charging of a composite sample during SEM scanning. Sample consists of alumina (left half) and silica (right half) and the SEM beam is moving from right-to-left (top) and from left-to-right (bottom).

Discussion

Apart from studying the artifacts of SEM images, our solver can be employed to analyze other problems involving collisions of low- to medium-energy electrons with insulators and semiconductors, e.g., particle detectors and solid-state photomultipliers [5]. However, it will take some time and effort to convince the particle physics community about the correctness and benefits of the continuum approach to the problems that are still almost exclusively studied by particle-based MC methods.

Neil Budko¹, Behrouz Raftari¹ and Cornelis (Kees) Vuik¹

¹ Delft University of Technology, Netherlands

References


Educational Committee
32nd ECMI Modelling Week in Novi Sad

The 32nd ECMI Mathematical Modelling Week was organized by the Department of Mathematics and Informatics, Faculty of Sciences, University of Novi Sad, and took place on July 15-22, 2018 at University of Novi Sad campus.

There were 67 students from 21 universities from all over Europe participating in 32nd ECMI Modelling Week. They were divided into 12 groups depending on the modelling problem of consideration.

Students who participated were mostly students from ECMI centres who previously got in touch with their local contact to agree on the participation. All of them had to apply (by filling in the online registration form) by May 15, 2018.

The event had several places for students from non-ECMI universities. Students from non-ECMI institutions was in obligation to send to the organizers the additional documents motivating their wish and eligibility for participation in the event.

The ECMI awarded 11 students who were not supported by their universities.

The projects covered many different topics, and all the participants were very motivated by the topic, the instructor and the team. The projects were as follows:

Modelling Problems

1. Optimization of plane assembly process, instructor: Maria Churilova (mathematical background: basic mechanics, optimization methods)
2. Modelling drilling cuttings formation, instructor: Tatiana Pogarskaia (mathematical background: mechanics, stochastic processes)
3. Modelling groundwater flow in aquifers, instructor: Ercilia Sousa (mathematical
background: partial differential equations, numerical analysis, Matlab programming skills)

4. Wind power prediction, instructor: Tihomir Ivanov (mathematical background: no specific requirements, but some knowledge in one of the following: PDE modelling, time series analysis, numerical analysis, was helpful)

5. Forecasting allergen’s concentrations, instructor: Marko Nedeljkov (mathematical background: partial differential equation, stochastics)

6. Storing your random objects, instructor: Thomas Götz

7. Imaging the body with light: mathematical and numerical challenges, instructor: Paola Causin (mathematical background: Calculus, Physics, Numerical Analysis, Matlab programming)

8. Modelling effect of time delay for large network of seismic monitor, instructor: Christophe Picard (mathematical background: linear algebra, signal processing, graphs)

9. Modelling of Ice around Cooling Pipes, instructor: Jürgen Dölz (mathematical background: stationary heat equation, Bernoulli’s free boundary problem, boundary integral equations)

10. The espresso-coffee problem, instructor: Milana Ćolić (mathematical background: Calculus, Modeling with PDE’s, Numerical Analysis)

11. Diffusion and anomalous diffusion models: simulation and application to biological data, instructor: Michal Balcerek (mathematical background: probability theory, stochastic processes and time series, modelling of random variables and stochastic processes in Matlab (preferably))

12. Modelling human interactions across a city with graphs, instructor: Olivera Novović (mathematical background:

graph theory, linear algebra, probability theory)

All groups have presented the solutions of the problems on the last day of the Modelling week, and on that occasion all instructors said that they were very satisfied with the presented solutions. The participants had deadline for submitting reports until October, 15 and all groups did it on time. Reports have been published on the web site of the event.

Besides group working, the participants had the opportunity to enjoy the city, which spreads along the Danube river. There was also a guided visit to the castle and a dinner, with a view over the city.

The organizers had for sure a lot of work but it was so much fun! It is an amazing event, for all of those involved.

All details about participants, modelling problems, and reports can be found at https://sites.dmi.uns.ac.rs/ecmimw2018

Cláudia Nunes¹, and Danijela Rajter-Čirić²
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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 2018 our activities were focussed on two main events. The second SIG workshop took place in Limerick (March 21 - 23). More than 70 participants from 16 European countries discussed about maths for virtual product development, MSO of production systems, as well as recent energy optimization issues in robotics. Specific highlights were a public panel discussion on the position of mathematics within the future of digital manufacturing and a round table on mathematics in Horizon2020 and FP9.

During the ECMI conference in Budapest we organized a minisymposium highlighting new mathematics to optimize production systems.

Finally, we plan to submit a proposal for a European Joint Doctorate for maths in digital manufacturing in the next ITN call.

Dietmar Hömberg

Weierstraß-Institut and Technische Universität Berlin

The four industrial revolutions (from C. Roser at AllAboutLean.com)
Modelling, Simulation and Optimization in Electrical Engineering

Purpose

Electrical engineering is an important technology for many recent societal and industrial developments. It includes the investigation and application of electricity, electronics, and electromagnetism. For example, smartphones are using semiconductors based on nanometer technology for processing data. At the same time they are connected to the internet through antennas for exchanging data with cell towers which are tens of kilometers away. More generally, equipment for mobile communication is used to control many other applications, e.g. in health care, banking, security, autonomous driving or energy distribution. Particularly, the transition towards sustainable energy requires the improvement of electrical infrastructure, again, from small scale, e.g. household devices, electric machines, up to power grids.

Opportunities

The Special Interest Group MSOEE (Modeling, Simulation and Optimization in Electrical Engineering) brings together mathematicians, simulation engineers and practitioners from academia and industry. The group has agreed on a broad understanding of the application field: it includes circuit simulation, computational electromagnetism (from low to high frequencies, up to optics), electrochemistry, material science with focus on semiconductors and plasma physics. Current methodological research is carried out on modeling with differential equations, model order reduction, multiscale and multirate methods, structure preservation and uncertainty quantification.

Electric machine model. Image: Robert Bosch GmbH
Activities

The special interest group MSOEE was established in 2018. Its roots can be traced back to 1997 where Michael Günther and Ralf Hiptmair founded a first group on Scientific Computing in Electronic Industry (ECMI SIG SCEI). The new SIG met first in January 2019 during a kickoff meeting at the Weierstrass Institute (WIAS) in Berlin which was organized by Nella Rotundo, Patricio Farrell and Dirk Peschka. The next event is a multi-session minisymposium at ICIAM 2019.

The interest group is about to organize a joint European research network with one focus on machine learning in modelling, simulation and optimization of electrical engineering applications. If you are interested, please contact us and consider becoming a member by subscribing to the mailing list: https://mail.gsc.ce.tu-darmstadt.de/mailman/listinfo/msoee.

Stefan Kurz and Sebastian Schöps

Robert Bosch GmbH and Technische Universität Darmstadt
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 for organic photovoltaics, supercapacitors, and solar fuels. The kick-off meeting for this SIG, “Nanostructures for Photovoltaics and Energy Storage”, also included electrothermal modelling and simulation of organic materials and devices. There is now a major and timely international focus on lithium-ion batteries.

Purpose

We address the challenges posed by the way energy will be 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, e.g. from industry, working in fields such as batteries, thermoelectricity, nano-scale optics, organic/polymer electronics such as organic LEDs and storage systems are presently the key stakeholders to which this SIG reaches with its activities. Contributions relating to energy distribution and networks are also welcome.

There has been rapid growth of a network of applied mathematicians who are working on batteries. Growth has been partially driven by the Multi-Scale Modelling project of the Faraday Institution (UK), which aims to bring together mathematicians, engineers, and experimentalists in order to develop new models of lithium-ion batteries that capture physical process across a vast range of length and time scales. Current research on batteries includes:

- Systematic derivation of multi-scale models that account for
electrochemistry, thermal effects, mechanics, and phase separation.

- Asymptotic reduction and solution of comprehensive physical models.
- Modelling battery degradation and thermal runaway.
- Development of fast and robust open-source software for model simulation, parameter estimation, and design optimisation.

Activities

- While at the University of Limerick, Iain Moyles (now at York U., Canada) was awarded a 2018 Charlemont Grant from the Royal Irish Academy to work on thermal runaway in lithium-ion batteries in collaboration with Matthew Hennessy (Oxford, UK), Tim Myers (CRM, Spain), and Brian Wetton (UBC, Canada). The aim of this project is to predict the conditions that lead to rapid heat generation in a battery pack and develop simplified models that can be used in on-board thermal management systems.
- At the ECMI annual conference in Budapest, the SIG’s activities were showcased in a minisymposium on “Material design and performance in sustainable energies”. Contributors spoke about solar cells, batteries, wind power, and connections to material science modelling.
- At the 2018 British Applied Maths Colloquium, Jamie Foster (U. Portsmouth, UK) and Mat Hunt (U. Warwick, UK) organised a mini-symposium on “Mathematical modelling of lithium-ion batteries”. The sessions featured eight talks by researchers across the UK.
- Matthew Hennessy and Iain Moyles will be running a mini-symposium entitled “Mathematical advances in lithium-ion batteries” at ICIAM 2019, where 15 speakers from 8 institutions across the world will speak about their research.

Matthew G. Hennessy¹, Andreas Münch¹, and Barbara Wagner²

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Computational Finance and Energy Markets

The ECMI Special Interest Group (SIG) Computational Finance and Energy Markets 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. Since ECMI-2016 in Santiago de Compostela the focus was extended to also include Energy Markets. 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 was active at ECMI-2018 in Budapest, Hungary.

Purpose

At ECMI-2018 the Special Interest Group on Computational Finance and Energy Markets organized a minisymposium Computational Methods for Finance and Energy Markets. We brought together again twelve speakers from academia and industry.

The speakers came from the Wrocław University of Science and Technology (Poland), University of Southern Denmark (Odense), TU Denmark (Kongens Lyngby), Max Planck Institute Leipzig (Germany), Bergische Universität Wuppertal (Germany), the University of Sussex (Brighton, UK), CMAPRE/ISEG of University of Lisbon (Portugal), ITWM (Kaiserslautern, Germany), Pázmány Péter Catholic University (Budapest, Hungary), the University of Indonesia (Jakarta) and Uniper Global Commodities SE (Düsseldorf, Germany).

The computational complexity of mathematical models employed in financial mathematics has witnessed a tremendous growth. Advanced numerical techniques are imperative for most present-day applications in the financial industry.

The aim of this minisymposium was to present the most recent developments of effective and robust numerical schemes for solving linear and nonlinear problems arising from the mathematical theory of pricing financial derivatives and commodities and related financial products. These approaches vary in departing directly from the system of stochastic differential equations (SDEs, involving SABR dynamics)
to approaches for the derived partial differential equations (PDEs). The SDE group focuses on fast Monte-Carlo methods involving multilevel price estimation of jump diffusion driven assets and multi-step spline schemes for backward stochastic differential equations. Efficiently modeling stochastic correlation is a hot topic. The PDE group discussed efficient finite difference methods (high-order schemes with stochastic volatility and jumps in return).

In recent years we observe an increasing interest in mathematical methods for energy markets as well. The rapid changes in energy trading within the last two decades has attracted many researchers in academia and industry. Their aim is to adequately model energy prices and typically also to design methods and guidelines for risk management challenges.

Typical topics addressed at ECMI-2018 were price modeling for the German secondary balancing power market, gas prices dynamics, Heston stochastic local volatility model in commodity markets, coupling reserve allocation and renewals, and proxy hedging of bunker fuel.

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). This also covers the important aspect in modeling Financial Risk. The Special Interest Group is open for further participation.

"Counterparty exposure has become the key element of financial risk management, highlighted by the bankruptcy of the investment bank Lehman Brothers and failure of other high profile institutions such as Bear Sterns, AIG and Fannie Mae.

Unlike the credit risk for a loan, when only the lending banking organization faces the risk of loss, counterparty exposure creates a bilateral risk of loss. The future market value of the exposure and the counterparty’s credit quality are uncertain and may vary over time as underlying market factors change. Standard credit risk models cannot explain the observed clustering of default, sometimes described as "credit contagion". Counterparty risk is a potential channel of credit contagion, and its modelling needs complex approaches. Regulators try to mitigate counterparty risk by increasing capital reserve requirements. A more market-conform solution is Credit Valuation Adjustments (CVAs), when the price an investor requires for a product is reduced in the trade with a defaultrisky counterparty as opposed to a default free one. However, various approaches, going beyond CVA also appear in the literature, but they slowly gain acceptance in the financial industry."

Activities

- At the regularly-held biennial ICCF Conferences (2015, 2017, 2019) and at the ECMI Conferences special SIG-Meetings are held.

Projects

- Matthias Ehrhardt is leader of the bilateral German-Portuguese Project FRACTAL – FRActional models and CompuTationAL Finance, financed by DAAD (01/2019-12/2020)
- He is member of the bilateral German-Hungarian Project CSITI – Coupled Systems and Innovative Time Integrators, financed by DAAD (01/2019-12/2020)
- He is leader of the bilateral German-South African Project IMPROVE – Interest rate Modelling with Applications to Pricing of Swaptions and Barrier Options, financed by DAAD (04/2018-09/2018)
He is leader of the bilateral German-Slovakian Project ENANEFA – Efficient Numerical Approximation of Nonlinear Equations in Financial Applications, financed by DAAD (01/2018-12/2019)

Carlos Vazquez (Univ. A Coruña, Spain) & Kees Oosterlee (CWI Amsterdam, NL): EID WAKEUPCALL – Applied mathematics for risk measures in finance and insurance, in the wake of the crisis (01/2015-01/2019) https://www.narcis.nl/research/RecordID/OND1358916


Rafał Weron (University of Wroclaw, Poland): Investigating Market Microstructure and short-term price forecasting in intra-day electricity markets https://www.ii.pwr.edu.pl/~rweron/Grant

Mini-Symposia / Workshops Done


Mini-Symposia / Workshops Planned

ICCF Conference, Universidade da Coruña, July 8-12, 2019.

- BIRS Workshop New Challenges in Energy Markets – Data Analytics, Modelling and Numerics, Sep 22-27, 2019, Banff Research Centre, Canada (Organizers: M. Coulon, C. Vazquez, T. Ware).
- European Study Group with Industry (ESGI), Wuppertal, March 2020 (Organizers: M. Ehrhardt, M. Günther)
- Lorentz Center Workshop Applied Mathematics Techniques for Energy Markets in Transition, Sep 2021 Leiden, NL.

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 considered the fourth industrial revolution. 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 the 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. The extraction of meaningful information from data is one of the main tasks of Statistics. In the presence of big data the majority of the usual techniques for statistical analysis cannot 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 the presence of distributed architectures (for e.g. the well known MapReduce paradigm). Unfortunately in many situations such procedures cannot 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. 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 minisymposium of the SIG took place during the conference ECMI 2018, Budapest, June 18-22, 2018
▶ The MSC-ITN-EID European project BIGMATH has been funded by the EU (grant number 812912). It started in October 2018. The project, coordinated by Università degli Studi di Milano, includes other 3 academic centres (IST Lisbon, TU-Eindhoven, University of Novi Sad) and 6 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 2019

▶ A kickoff workshop to present BIMGATH and its activities is planned in Milan on March 11, 2019.
▶ Three PhD courses on Large scale linear algebra, Stochastic geometric techniques, Data mining for Big Data will be held during 2019. Such courses are related with the BIMGATH project, and will be offered by the 4 academic partners, who are also members of the SIG.
▶ Two minisymposia, one of the SIG and one of the BIMGATH project, will be organized during the conference ICIAM 2019, Valencia, July 15-19, 2019.

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

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

The Liquid Crystals, Elastomers and Biological Applications Special Interest Group focuses on the mathematical theories and modelling of soft materials that are intermediate between solids and liquids, with special emphasis on synergistic links between theory, experiment, simulations and industrial applications.

Purpose

The ECMI Special Interest Group in Liquid Crystals, Elastomers and Biological Applications is led by Apala Majumdar (University of Bath) and Nigel Mottram (University of Strathclyde). This Special Interest Group is focused on the theories and applications of soft materials, anisotropic or directional materials and how the directionality can be best exploited for new applications in materials science and technology. The group is particularly well connected with the British Liquid Crystal Society and the UK Fluids Network. In particular, Mottram co-leads a UK Fluids Special Interest Group on "Fluid dynamics of liquid crystalline materials" that brings together researchers from at least thirteen UK universities and industrial representatives. The primary goal of this ECMI Special Interest Group is to bring together the European research communities in soft and anisotropic matter, engage in interdisciplinary research and connect with relevant industries e.g. Merck, Sharp etc. The leaders have taken several initiatives in this direction as outlined below.

Opportunities and Activities

Apala Majumdar is the Principal Investigator of a London Mathematical Society network
grant on "Anisotropic Materials". This grant has three nodes - Bath (led by Majumdar), Oxford (led by Ian Griffiths) and Strathclyde (led by Nigel Mottram). The network will organise three meetings in the 2018-2019 academic year, of which two have taken place in April 2019 (Bath) and May 2019 (Oxford). The third meeting will take place in Strathclyde in September 2019. More details can be found at https://people.maths.ox.ac.uk/gri4/bos.shtml

Majumdar is the Principal Investigator for a Bath-Chile-Mexico network, which spans four institutions in South America: the Centre for Mathematical Modelling (CMM) at the Universidad de Chile, the Pontificia Universidad Católica de Chile, National Autonomous University of Mexico and CIMAT in Mexico. This network has hosted one workshop on "Applied and Interdisciplinary Mathematics" at the CMM Chile in March 2019; more details can be found at http://eventos.cmm.uchile.cl/cmmubath2019/. Further workshops are planned under this umbrella.

Mottram and Majumdar have given invited research talks at the workshops on "Optimal design of Complex Matter" and "Optimal design of soft matter - including a celebration of Women in Materials Science (WMS)" at Cambridge, as part of the thematic programme on "The mathematical design of new materials" at the Isaac Newton Institute from January to June 2019. Majumdar was the proposer and one of the organisers for the "Celebration of Women in Materials Science" event.

Researchers are welcome to contact the Special Interest Group if they wish to be part of the group, or the London Mathematical Society network or UK Fluids Special Interest Group on "Fluid dynamics of liquid crystalline materials".

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Future Activities

The organisers aim to further branch out the SIG activities by connecting with CESAER, a non-profit association of leading universities of science and technology in Europe, and with the new Fraunhofer Centre for Applied Photonics at Strathclyde.

Apala Majumdar and Nigel Mottram
Shape and Size in Medicine, Biotechnology and Materials Science

Thanks to the development of information technologies and new imaging techniques, 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. Our Special Interest Group (SIG) is concerned to emphasize topics which are relevant in medicine, biotechnology and materials science.

Purpose

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, random media can be characterized using stochastic shape models whose parameters are determined from images using mathematical morphology, then from stochastic models, new samples can be generated and their physical properties computed.

Opportunities

From the mathematical point of view, shape analysis uses a variety of mathematical tools from differential geometry, Hamilton-Jacobi PDEs, 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

Main foreseen activity:

- Workshop in Paris to coordinate application to Marie S. Curie ITN network, Fall 2019, precise date to be decided.

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 “Mathematical Modelling in Biomedical Applications” at ECMI 2018 in Budapest and the three day workshop “Modelling and experiments in drug delivery systems” at University of Glasgow in Scotland. These events brought together in excess of 70 participants including mathematical modellers, experimentalists, industrialists and clinicians from several countries across Europe (UK, Ireland, France, Italy, Portugal, Switzerland, Spain, Ukraine) and beyond (Brazil, China and the US).

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 co-ordinate 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 (MEDDS2018) workshop was held at the University of Glasgow in June 2016, under the auspices of the SIG. Over 50 delegates covering modellers, experimentalists, industrialists and clinicians attended the event which featured an industry problem solving session. David Prime from GlaxoSmithKline presented a problem on drug delivery to the lung, while Prof Anthony Chalmers presented a clinical problem on drug delivery to brain tumours.
Keynote speakers included David Saylor from the US Food and Drug Administration (FDA), Prof Paolo Netti from University of Naples Federico II and Prof Keith Oldroyd from the Golden Jubilee Hospital in Glasgow.

The first day of the meeting was designated the 'Industrial Focus' while the third day was designated the 'Stents Focus'. Over 30 MEDDS Abstracts were accepted and presented in oral and poster formats. The event was a huge success. Many new collaborations have been formed and there are ongoing discussions in relation to taking the industry problems forward.

Mathematical Modelling in Biomedical Applications

We organised the above titled minisymposium at the 20th European Conference on Mathematics for Industry (ECMI 2018) in Hungary. There were six contributed talks from members of the SIG covering stents research as well as problems more broadly in cardiovascular, drug delivery and medical device applications. The talks included:

- **Modelling Biology After Implantation of a Drug Eluting Stent**, Prof William Lee, University of Huddersfield (UK).
- **Modelling Drug Release from Polymer-Free Stents with Microporous Surfaces and Drug-Filled Stents**, Dr Tuoi Vo, University of Limerick (Ireland).
- **Modeling the Effect of Flow on the ATP/ADP Concentration at the Endothelial Cell Surface**, Prof Abdul Barakat, Ecole Polytechnique (France).
- **Mathematically Modeling Drug Release from Solid Dispersions**, Dr Martin Meere, NUI Galway (Ireland).
- **Modelling Protein Adsorption and Optimisation of Novel Immunodiagnostic Devices**, Dr Dana Mackey, DIT (Ireland).
- **Electrical Conduction in Media with Microstructures**, Dr Daniele Andreucci, Sapienza Università di Roma (Italy).

SIG Committee Meeting

MEDDS 2018 also provided the opportunity for us to hold our SIG Committee meeting, which was preceded by a discussion session on the future of the SIG. We had always intended to broaden the scope of the SIG (and indeed MEDDS2018 was part of that). We have decided that the SIG should be renamed “Implantable devices and drug delivery system” moving forward.

Forthcoming Activities

The SIG has also proposed several future activities:

- The creation of a textbook which could be used as a teaching material, broadly in the area of biofluid mechanics and mass transport (in the context of implantable devices and drug delivery systems);
- The creation of a collaborative community supported by the FDA;
- The creation of a position paper by the SIG;
- The organisation of a mini-symposiums at ECMI 2020 in Limerick.

Those interested in becoming more involved in the SIG and these activities should contact Sean McGinty (sean.mcginty@glasgow.ac.uk).

Coordinator: Sean McGinty
University of Glasgow
Net Campus for Modelling Education and Industrial Mathematics

This ECMI Special Interest Group (SIG) was launched in 2017 following initiatives taken by ECMI’s Educational Committee. The aim of the SIG is to coordinate the ongoing activities at various ECMI centers in the field of online and digital education and to 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. This will complement the other strategic areas of ECMI curriculum development, modelling weeks, and supporting the mobility of students and staff.

Cutting edge knowledge in industrial mathematics is dispersed across small nodes of expertise. Online environments permit access to this knowledge as well as supporting innovative processes, training and educational needs that facilitate distributed consultation processes. The evolution from textbook to interactive multimedia environment creates a new learning paradigm. The advantage of this new learning environment includes its accessibility and portability, it permits flexible updates, dynamic editions, multi-/hypermedia tools from search facilities, the use of quiz-structures to animations, interactive exercises, remote lectures and video conferencing, amongst other things.

We aim to build a European digital environment and web-portal for applied and industrial mathematics. The more immediate goal is to share information and experience, in order to describe the best examples of web-based and interactive courses in applied mathematics and technologies. The courses should be based on customized content for specialist application areas. We envisage that this environment will be suitable for advanced students in applied mathematics and
engineering, (at BS and MS level) as well as for people in work who are continuing their education and professional development.

**Current State of the Pilot Online Course**

Since 2017 the ‘ECMI Modelling Course’ at the LUT Moodle has grown from 30 to a total of 60 students. Eight topics, covering a variety of applied problems, are available for further interested students to earn some first experiences of mathematical modelling, see for example Figure 1. The course is open for interested institutions to join and increase the existing numbers of participants and posed problems.

A very positive response to the course came from the German “Stifterverband” (foundation union), which rewarded Robert Rockenfeller, one of the initiators with the “Ars Legendi-Fakultätenpreis”, a prize for excellent teaching in tertiary institutions.

![Figure 1: Output from the ecological forest growth problem as posed by Virpi Junttila from LUT and realized by a student group from Koblenz. Thousands of trees of different type compete for light and space, modelled by logistic differential equations. Different colors account for different species, white means the tree has died.](image)

**Initiative to promote ECMI e-learning environment**

Our vision is to develop a set of courses (portal, virtual course portfolio, e-learning environment for IM) which would emerge from various ECMI-nodes, authored by colleagues from our SIG or by new members to our SIG.

**Call for Proposals**

We invite ECMI nodes to send suggestions for course topics along with a short abstract describing the course content. We are particularly interested in special topics of applied mathematics that are (1) of fresh current interest (2) are relevant for the MS and Phd students in industrial mathematics and (3) which are likely to raise interest also among people working in various R&D sectors in industry.

In a second phase we envision seed-funding of 2000 euros each for 4-5 courses to enable the actual content production and transformation of course material into the required “semi-professional” format and style. At this point we will define common guidelines on the style, format and academic criteria for such courses. Partners may also look for local sources of additional funding to produce the course.

This SIG poses a big challenge that should be approached as a gradual stepwise development. In order to generate polished professional digital environments one needs a lot of funds, digital professionals, and big sponsors. To get an ECMI-level process in motion, we should relax the ambition level at this stage, to generate version 0.1 so to speak: A good starting point is this collection of virtual courses in the ECMI-spirit (of industrial applications motivated in a problem solving spirit). We look forward to your proposals, which should consist of the following:

- Well written powerpoint slides,
- A list of background reading and references to literature or other web-materials,
- Exercise collection indicating what a student should be able to do.
- Perhaps a few indicative project topics.

**Coordinators:** Robert Rockenfeller\(^1\) and Matti Heiiö\(^2\)

\(^1\) University Koblenz-Landau, Germany
\(^2\) 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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(May 2019)
Mathematics with industry: driving innovation

Annual Report 2018

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:

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