Activities & Scientific Report

2023

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Centre Européen de Calcul Atomique et Moléculaire

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INTRODUCTION

The CECAM Flagship program for 2023 showcased 80 events hosted by Headquarters and the Nodes. 17 workshops and 1 school were held at EPFL, organized by 66 scientists based in 16 different countries. The infrastructure set up in the years of the pandemic enabled seamless support for hybrid formats for 6 of these workshops and for the school. It is, however, interesting to note that of the 811 participants to the 2023 events, 611 joined onsite demonstrating the clear preference of the community for in person participation. Informal interviews and replies to our post-event surveys indicate more fruitful scientific exchanges, networking, and easier planning of future collaborations as the main drivers of this preference. Importantly, the possibility of remote participation is appreciated both by organisers and participants as a tool to reduce the carbon footprint of the event, contribute to the quality of the talk (e.g. relevant speakers who may not be able to attend otherwise), and facilitate attendance from developing countries. Data confirms this, with – for example – ca 26% of online participants to HQ activities declaring an affiliation in developing countries.

Similar trends for in person and online participation were recorded for the 42 events that took place in the Nodes. 25 workshops (23 onsite and 2 hybrid) and 17 schools (14 onsite, 2 hybrid, 1 fully online) composed the program in the network, featuring 203 organisers from 20 different countries, and a total of 913 participants (605 onsite, 308 online).

In addition to the activities carried out within the Flagship program, several other initiatives were carried out in the year. In particular, the second part of the 2022-2023 season of the Mixed-Gen series comprised 5 lectures, with topics ranging from machine learning and data-based methods for applications in soft matter, biophysics and drug discovery (3 lectures), to the simulation of electrochemical systems, to non-equilibrium problems. In keeping up with the spirit of this series, 13 early career researchers had the opportunity to present their work in this context. The Mixed-Gen sessions are fully on line, with an average number of participants of ca. 130 attendees. Furthermore, the collaboration between CECAM and the Swiss NCCR MARVEL continued with the delivery of the ninth Classics in molecular and modeling lecture. The lecture – delivered by E.K.U. Gross and A. Rubio on the topic of time-dependent density functional theory - was held in hybrid format. More than 60 researchers at different stages of their career attended in person, joined by over 250 online participants. The third installment of the online series “From women’s eyes”, an effort to promote gender equality in computational sciences via shared experiences of leading female members of our community, was held on February 10 on the occasion of the UN day for women and girls in science.

Overall, the reports and descriptions of activities in the following clearly show that CECAM continues to act as a focal point for the community, providing a much-valued venue for scientific exchange, collaboration, and advanced training. The vibrant program of activities, determined via the refereed selection of bottom up proposals, balances emerging topics, more consolidated subjects and applications with clear potential for societal benefits, offering a unique environment for progress and world-wide outreach.

Physics-based hydrology: From the heterogeneous subsurface to dynamic catchments

Location: CECAM-ISR
Webpage : https://www.cecam.org/workshop-details/1147
Dates: Jan 10, 2023 - Jan 12, 2023

1 State of the art

Over the past decades, hydrology as a discipline has evolved in many ways. It is currently viewed as a key geoscience for understanding short- and long-term impact of global change. Within this broad discipline, hydrologists address a variety of water-related issues, from soil processes and vegetation, to surface- and groundwater, to biogeochemical transformation. In addition to the local scale processes, large-scale hydrology implies strong interactions between catchment dynamics and the climate system affecting both water quantity and quality. Resolving hydrological processes rigorously based on physics still poses serious challenges in spite of the significant progress. The main reason is that natural systems exhibit variability in space and time on multiple scales, requiring novel approaches that combine physics with probabilistic scaling concepts. It is only through physics-based bottom-up approaches combined with insightful synthesis of top-down approaches that hypotheses, theory and observations can converge.
With the increasing capabilities of computational sciences, powerful tools have emerged, advancing the field. While High Performance Computing opens interesting perspectives for advancing our understanding of transport processes across scales, from pore to catchment scale and beyond, physics-based descriptions are critical for identifying dominant couplings and suitable scale-dependent parametrizations. Furthermore, recent scientific discoveries show complex properties of water on the molecular scale. This calls for deeper understanding of water properties based on molecular interactions across the whole water phase diagram, affected by interfaces and confined geometries such as pores.

2 Major outcomes

A tour through stochastic subsurface hydrology
The workshop presentations covered the entire subsurface, from the unsaturated zone (David Russo) to groundwater, and also included fractured media (Vlad Cvetkovic, Benoit Noetinger, Alessandro Lenci) and karst systems (Alessandro Passo). The subsurface is characterized by heterogeneous properties that vary over a wide range of scales. Many different methods such as travel-time distributions (Aldo Fiori), continuous-time random walk methods (Marco Dentz), analytical inclusion models (Gedeon Dagan), polynomial expansion methods (Valentina Ciriello), stochastic averaging and scaling (Ines DiDato, Daniel Tartakovsky), multipoint statistics (Philipp Renard) or machine learning methods (Alexandre Tartakovsky) were presented to address the challenge of accounting for heterogeneities in flow (Avinoam Rabinovich, Gerardo Severino) and transport (Alraune Zech) problems at field scales. We have also seen many of us move to regional or even catchment scales. Catchment-scale hydrological models (Alberto Bellin), including travel time quantification (Andrea Rinaldo), have been discussed and used in court cases (Howard Wheeler) or for groundwater recharge management (Daniel Kurtzman). The modelling studies presented were complemented by experimental studies. Analogous to the modelling studies, experimental methods quantifying heterogeneous subsurface properties were presented covering different spatial scales, such

as small-scale experiments on gas transport through heterogeneous unsaturated soils (Noam Weisbrod), inversion of field-scale geoelectric measurements (Ziv Moreno) to measurement of soil moisture by cosmic rays on a regional scale (Stefano Ferraris).
The workshop showed in an impressive way that the scientific community is aware that spatial heterogeneities play an important role in land surface processes and that they need to be adequately taken into account. Over the last 40 years, a variety of methods have been established for this purpose, both in modelling and in experimental methods. The final discussion showed that these methods are of course being further developed and applied to new problems and larger-scale issues.
However, it was also noted that there are two general major challenges to be overcome in a community effort: The development of a theory to account for heterogeneities for hydrological but also bio-geochemical processes in catchments and making methods usable for users in practice.

3 Community needs

It was clear in the meeting that communication and collaboration between various disciplines of water research is beneficial. This was an achievement of the symposium as participants were from a wide range of water related topics. More networking, conferences, meetings and joint funding opportunities will promote this further. In particular the combination of field investigations, laboratory experiments, theoretical research and numerical modeling is crucial to the community for advancing the science. When these are combined can we attempt to obtain the full picture of the processes which we are interested in. In terms of infrastructure, the main challenge is field experiments which are crucial for obtaining data. Efforts are currently being made in improving this aspect.
During the meeting it was also discussed that the importance of water related science should be made clearer to the general public and the government agencies in order to increase awareness of these issues.

4 Funding

Funding was not discussed specifically in the meeting; however, it is expected that collaborations and joint proposals will result from the interactions between participants. Typica funding channels are from government agencies such as the United States Environmental protection Agency, ERC:Smart Water Futures, Department of Energy, National Institute of Health and other agencies funding basic science. As the workshop was held in Israel, there are particular funding sources which encourage collaboration with Israeli Scientists such as US-Israel Agricultural Research and Development Fund.

5 Will these developments bring societal benefits?

The topic of the workshop is directly related a number of sustainability applications such as water management, climate change evaluation, remediation of contaminated water and CO2 geological storage. Water scarcity and insecurity is still a huge global problem. The field work, modeling efforts, theoretical developments and laboratory experiments reported and discussed in the workshop will be a contribution to the efforts in solving the water issues. In particular, an important aspect of the workshop is the research diversity that was present. There was a combination of various fields of research and research efforts related to water, for example the catchment scale, upper soil regions and groundwater. Another example is the combination of experiments, field work and modeling. These combinations lead to a broader understanding of the water issues which humanity is faced with and to developing better tools for dealing with these issues. It is worth noting that these water issues are part of the larger topic of water-food-energy nexus which is of significant importance to society.

6 Organizers list

Attinger, Sabine
Helmholtz Centre for Environmental Research, Germany
Destouni, Gia
Stockholm Univeristy, Sweden
Fiori, Aldo
Roma Tre University, Italy
Rabinovich, Avinoam
Tel Aviv University, Israel
Tartakovsky, Daniel
Stanford University, United States

International Workshop on Computational Physics and Materials Science: Total Energy and Force Methods

Location: ICTP, Trieste, Italy
Webpage : https://www.cecam.org/workshop-details/1151
Dates: Jan 11, 2023 - Jan 13, 2023

1 State of the art

This is a renowned biennial workshop about recent progress in electronic structure methods and their applications. It is one of the most prominent international conferences in its field, filling the gap between the large-scale Psi-k conference and small-scale workshops focused on one approach or a single class of systems. The aim is a critical discussion of methods and challenging applications. The “Total Energy” workshop has been held since 1984, making it one of the longest running, established events in the scientific calendar. Since 1987 it is held at ICTP in Trieste every two years; in the even years a smaller workshop is held at different locations worldwide (e.g., in 2018 in Cambridge UK). As such, it has become one of the most popular, regular events of the international electronic-structure community, with a two-pronged focus on recent progress in electronic-structure methods, and in their applications to a steadily increasing range of complex materials and systems. Widespread approaches used in the electronic structure community include DFT, TDDFT, GW-BSE, DMFT, and quantum Monte Carlo methods, which provide the foundation for computing many physical and chemical properties of solids, interfaces, liquids, and low-dimensional systems. There are numerous challenging applications for which the approximations used in these formalisms, or their technical limitations, do not yet permit accurate quantitative predictions of some properties of materials or electronic phenomena. The goal of the workshop is to provide a broad view of recent developments, current challenges, and future directions of the field. Moreover, it will be a forum where approaches that have shown some promise more recently, such as machine learning or quantum computing, are explored, and where possibilities to combine different methods are discussed.

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2 Major outcomes

The 21st International Workshop on Computational Physics and Materials Science: Total Energy and Force Methods is a platform to discuss recent progress in electronic structure methods and their applications. It is one of the most prominent international conferences in its field, filling the gap between the large-scale Psi-k conference and small-scale workshops focused on one approach or a single class of systems. As such, the topics of discussions tried to cover the main developments that have taken place in the last period. A large part of the workshop was dedicated to progress in the description of excited states and their dynamics. This included: extension of many-body perturbation theory to address multi-particle excitations in the solid state; expansions of linear scaling methods to address excitations in large systems, such as metallic nanoparticles and disordered systems; development of functionals to obtain spectral densities; applications of ensemble density functional theory to the description of excited states. The Hubbard U method is gaining ground towards being able to calculate the U parameter from first principles in an efficient and physically sound and consistent way. Highlights were also reported for the description of vibrational dynamics, with successes regarding anharmonic effects, non-adiabatic dynamics, and thermal transport. Regarding magnetism, there were discussions of 2D materials, surfaces, and interfaces. Monte Carlo methods have shown progress in the description of realistic systems, like hydrogen at high pressure, and for optimization problems.
There were also sessions dedicated to the two methodological revolutions that are in progress: that of machine learning methods, that was here specially applied to interatomic potentials, where neural-network and other potentials have taken the field by storm and represented an epochal change in how interatomic potentials are described and developed; and that of quantum computing, which is believed to also bear a huge potential, but which seems to be still at an earlier stage of development and which still has to solve considerable challenges, mainly due to the still limited availability and operability of physical qubits.
Finally, during the workshop, the Walter Kohn Prize was awarded to Debashree Ghosh, in recognition of her pathbreaking work in developing novel quantum chemical tools for materials design and the study of biological function. During the ceremony, Debashree Ghosh gave a talk entitled "Machine learning the configuration space using matrix product states", and was introduced, among others, by Nobel Laureate Roald Hoffmann.

3 Community needs

The 21st International Workshop on Computational Physics and Materials Science: Total Energy and Force Methods is a platform to discuss recent progress in electronic structure methods and their applications. This is a very broad community, with a few tens of thousands of researchers active only in Europe. Regarding the computational infrastructure, the community relies on well-established codes, some freely available, some commercially available, that have been developed over the last 3-4 decades, each of them relying on an organized group of developers. Moreover, the community is one of the biggest users of the existing HPC infrastructure, in Europe and elsewhere. Currently, the main trends regard the extension of codes to GPUs, and the creation of shared platforms for automated and/or high-throughput calculations, as well as the creation of large databases with calculated results.
The community has a strong connection with experimentalists in most sub-fields.
The community already makes large use of the possibilities offered by CECAM to organize workshops and events; this is highly appreciated and should remain so.

4 Funding

The community is very vast, counting a few tens of thousands of researchers only in Europe, and makes ample use of known sources of funding, including national and European funding schemes. Just to cite on of the most prominent, the MAX Center of Excellence (MAterials design at the eXascale Centre of Excellence) was established with European funding. Given the size of the workshop, with about 150 participants, there were no unique official discussions on joint proposals, though subsets of participants discussed these possibilities at informal level.

5 Will these developments bring societal benefits?

Electronic structure simulations are nowadays used also in industry, specially, but not only, the electronic industry and pharmaceutical industry. It is established that electronic structure methods are widely employed in materials and chemicals discovery, development and optimization, for applications ranging from electronics, through pharmaceuticals, to catalysts for the petrochemical industry. It is employed in two main ways: either for high-throughput investigation of many candidate materials, as a pre-screening to simplify the experimental search, or as a complementary tool to characterize materials and processes, complementary to experimental characterization techniques. This is reflected also in the funding possibilities, both because large technological industries fund and maintain their own groups performing electronic structure calculations, and because often research groups working on these simulations manage to become partners in large funding initiatives, even when these have mainly an orientation towards practical applications.

6 Organizers list

Biermann, Silke
Ecole Polytechnique, France
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University of Rome Sapienza, Italy
Saha-Dasgupta, Tanusri
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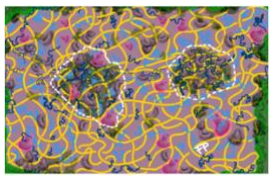
ICTP, Italy



Liquid, soft, alive: identifying the biological questions in the physics of cells

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1129
Dates: Feb 13, 2023 - Feb 16, 2023

1 State of the art

During the past decade there has been a shift in the way equilibrium concepts in soft matter and statistical physics have been employed to understand diverse problems in biology based on liquid-liquid phase separation (LLPS), macromolecular crowding, or formation of equilibrium clusters and aggregates (condensates). A common aspect of all such processes is the likely existence of phase diagrams with multiple stable or metastable polymorphic disordered liquid states [1]. However, unlike the passive phase behavior that is observed in natural and man-made phase separation processes (well understood since long ago), cellular LLPS processes at work in living systems are intrinsically non- equilibrium as a result of the intricate array of internal and external chemostats and mass/charge currents. On the one hand, understanding the fundamental mechanism of such non-equilibrium phase separation is crucial for better understanding the functioning (and malfunctioning) of the cell. On the other hand, the better the inner workings of the cell are understood at a fundamental level, the more researchers can get inspiration for creating soft matter physics analogs pointing to new strategies for novel functional materials design.
This workshop aimed at establishing an environment for fertile cross-talk between cell biologists and soft matter physicists who are interested to run experiments and model the non-equilibrium processes that govern key cellular processes. The primary objective of such cross-fertilization was to clearly identify the main biological questions for physicists to address. The second strong objective of the proposed workshop was to discuss state-of-the-art computational approaches bridging length- and time-scales to study these complex soft matter and bio-molecular systems.

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2 Major outcomes

The workshop confirmed that there is vigorous research activity involving biologists, chemists and physicists, which revolves around the central question of how a complex dynamic environment can organize and control multiple (bio)chemical processes in parallel. Understanding the functioning of such complex microreactors is also intimately connected with several key biological processes on the cellular level, and also with the formation of the protocells.

The participants of the workshop extensively discussed topics such as:

1. Liquid-liquid phase separation:
    a. condensates in auxin-based signaling pathways in plant cells.
    b. condensates in neuron synapses (Milovanovic),
    c. Material properties of a bacterial derived condensate (Lasker).
    d. LLPS and molecular crowding effects on folding and translocation process of a bacterial toxin (Chenal).
    e. Establishing a molecular grammar (Mittal), correlating sequences of amino acids with phase behavior.
    f. Alternatively, a more generic set of rules, for example the existence of highly charged regions and/or the existence of intrinsically disordered regions in the protein (Schuler).
    g. Activity-driven condensate formation in plants (Strader), hydrodynamic effects on activity-driven aggregate formation (Pagonabarraga)
    h. Liquid-liquid separation in systems of active ring polymers (Likos)
2. Protein aggregation (Garai)
3. DNA-coated colloids (Angioletti-Uberti)
4. Macromolecular crowding

Crowding effects on fold-switching proteins, detailed quantitative analyses of a proto-typical model macromolecular crowder (Ficoll).

Outcomes & new results:

The most valuable outcome of the meeting is the initiation of a fruitful cross-talk among otherwise rarely connected communities. The workshop offered a balanced mixture of biologists, chemists, and physicists who engaged in lively discussions throughout the duration of the event. The common conception seems to be that there is still a gap between the complexity of the biological systems and universality of the physical and computational models used to describe them, but that there is a huge recent progress in closing this gap. We have seen reports on experiments in biological systems with impressive quantitative details that enable new computational approaches to be developed, tested and applied in the future.

3 Community needs

The topic covered within the workshop is highly interdisciplinary and there is an urgent need for the crosstalk between computational/experimental physics and biology. Within our meeting, we have initiated and established such cross-talk. A great majority of the participants attending the meeting agreed that the interdisciplinary composition of the current workshop was fruitful and enthusiastically supported the idea of similar meetings on the topic taking place regularly in the future. A continuation of this workshop in the form of a periodic meeting is thus an excellent idea.

Moreover, the mixture of experimental and computational experts among the attendees seems to be the key to ensure the best possible progress of the field in the future. In terms of computational resources, the bottleneck does not seem to be computational power, but rather the development of appropriate model systems that will be able to address both universal physics and biochemical specificity of the relevant processes related to LLPS and biomolecular condensation.

4 Funding

Several participants of the workshop are already a part of the initiative to set up a European Research Training Network on liquid-liquid phase separation in a non-biological context. Such a network, if successful, will focus on understanding the nonequilibrium control of the phase separation process, and its use to design novel responsive materials. It will nicely complement several other activities related to biological aspects of LLPS. CECAM is associated with the

proposal, which promises a real synergistic effect: enhancing the impact of the network training program, and at the same time enriching the training activities at CECAM.

5 Will these developments bring societal benefits?

The role of LLPS in basic processes at the core of life has contributed to bringing soft matter physics closer to fundamental questions that arise in cell biology and prebiotic chemistry.
A fundamental understanding of the non-equilibrium control of biomolecular condensation will be very important for society, as it might bring upon improved understanding of functioning of biological systems, as well as the molecular origin of a variety of diseases. A better understanding of these processes will inevitably result in the development of novel treatment strategies in medicine.
Biological systems can achieve remarkable efficiency and selectivity, but thus far, the concept of driven LLPS has barely been exploited in man-made devices, and protein aggregation remains a challenge for drug formulations. Better understanding of the interplay between equilibrium thermodynamic driving forces and nonequilibrium activity can open new strategies to design biomimetic separation processes and new materials utilizing such mechanisms.

6 Participant list

Organizers

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Memorial University, Canada

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Chenal, Alexandre - Institut Pasteur, France
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Schuler, Benjamin - University of Zurich, Switzerland
Sear, Richard - University of Surrey, United Kingdom
Strader, Lucia - Duke University, United States
Wallin, Stefan - Memorial University of Newfoundland, Canada

Actively Learning Materials Science (ALMS 2023)

Location: CECAM-FI
Webpage : https://www.cecam.org/workshop-details/1212
Dates: Feb 27, 2023 - Mar 3, 2023

1 State of the art

The influx of machine learning algorithms from computer science into computational materials science (MS) has led to developments of innovative computational methodologies and opened up novel routes to addressing outstanding problems. Of particular interest are active learning (AL) algorithms, such as Bayesan optimization, where machine learning datasets are collected on-the-fly in the search for optimal solutions. AL methods were employed with considerable success to optimal design of experiments, efficient traversal of complicated search spaces for electronic structure simulations, hyperparameter optimization, high throughput screening and in automated laboratory discoveries.
The strength of AL techniques is that the machine learning model selects the data to include into the dataset via acquisition strategies. The requested data points can then be evaluated via computation or experiment and included into the model iteratively, until the optimal solution converges. The resulting compact, maximally informative datasets make AL particularly suitable for applications where data is scarce or data acquisition expensive. In this way, AL has helped accelerate materials discovery away from big-data and free of human bias. Despite recent successes, future applications of AL on experimental data are slow, given that key data infrastructure is still lacking. Working with multiple objectives, or multidimensional data remains challenging. Novel method development across the research field is needed to advance AL techniques and associated frameworks in materials research.
The Actively Learning Materials Science (AL4MS) focused on two key objectives, both from a pedagogical (first part of the event) as well as from an advanced perspective (second part of the event): 1) How could data infrastructures and AL algorithm development advance experimental materials discovery? 2) How could we combine multiple channels of information in the same AL model?

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2 Major outcomes

The introductory part of the workshop paved the way to an overview of active learning methods, e.g. Bayesian optimization and reinforcement learning, in the context of atomistic modelling, experiments, and machine learning potential generation. The relevance of FAIR protocols and automated workflows was also highlighted through a dedicated lecture + hands-on session. Tutorials used publicly available open source and documented codes.
The workshop program focused on active learning approaches for optimizing model prediction or target materials properties. Several contributions presented active learning methods with Bayesian optimization or reinforcement learning, but also with decision tree models. Technical discussions on state-of-the-art algorithms featured tailored acquisition functions for Bayesian approaches, and semi-supervised methods to circumvent missing data.
As a natural byproduct of the interest in Bayesian optimization algorithms, the workshop participants explored in rich detail the methods to predict model uncertainty and dataset curation. There was discussion about ensemble models, Bayesian approaches, or approaches based on the statistical/geometrical properties of the training set and the representation used to encode the information in the latter.
In relation to materials chemistry, AL4MS featured diverse applications ranging from energy materials (perovskites and batteries), to metallurgy and chemical reactions. The exploitation of information between experiments and simulations has been considered. There were discussions on how to leverage experimental data to produce better theoretical models, and how to exploit descriptors from simulations to better predict experimental outcomes.
The workshop also highlighted possible emerging research trends: in particular, multi-modality models, which use information from various sources such as text, images, and spectra. We also heard about multi-fidelity models, which harness data from sources with different fidelity levels, such as well-controlled experiments versus less controlled sources like literature. While it is crucial to use reliable and trustworthy data sources for machine learning, the information therein can be (too) little, such as it might also be beneficial to leverage information from multiple sources, so as to train a more informed model.
Throughout the conference, the importance of cross-contamination of expertise was a prominent and recurring theme. Participants voiced the need to foster interactions between communities, by identifying pressing and realistic problems, during panel discussions and presentations. The presence of leaders in atomistic modelling, computer science, machine learning, experimentalists, and industry representatives enabled an interdisciplinary exchange of perspectives and experiences. Our workshop was indeed specifically designed to identify the needs of multi- and interdisciplinary cross-contamination.
All attendees (to our knowledge), including invited speakers, online participants, poster presenters, and young researchers attending their first conference on the topic, have expressed satisfaction with the structure, topics, and organization of the event. Our feedback collection analysis demonstrated a very high satisfaction overall (4.3/5), with the workshop organization (4.6/5) and facilities (4.5/5). The workshop was rated as a highly enjoyable experience (4.5/5). We received some comments with suggestions for topics to explore in a future workshop, e.g. “Federated learning, ML for other types of materials data e.g. images, graphs, time series”.

3 Community needs

The computational needs in machine-learning for materials science are twofold: 1) data generation and 2) machine-learning model training and evaluation. For 1), data is typically generated with electronic structure theory methods (e.g., density-functional theory). The electronic structure theory community is well established with mature methods and codes. Electronic structure theory is resource intensive, however, and requires access to large HPC resources, in particular, because machine-learning datasets are large. For 2), machine learning codes are typically not as complex as electronic structure theory codes. They also frequently utilize established machine-learning libraries like scikit learn, pytorch or tensor flow. Machine-learning training can be costly (e.g., large matrix inversion in kernel methods or time

intensive neural network training) and is frequently carried out on GPUs. Easy access to GPUs would facilitate model training.
The AL4MS purposefully widened the scope and brought together a diverse set of speakers from machine-learning method development, experiment and a variety of application domains. While machine-learning is progressing rapidly in computational materials science, experimental materials science is slower to catch on and data is scarcer and more heterogenous. AL4MS reached out to experimental work in e.g., biomaterials, photovoltaics and battery materials, but more outreach and networking of this kind is required in the future.
The development and application of machine-learning in materials science proliferated in recent years. Many workshops and conference symposia are organized on the topic. A CECAM workshop series would, in our opinion, not be required since many bottom-up workshop proposals are submitted on interesting machine-learning applications and problems. If CECAM felt a need to consolidate developments in machine-learning in materials science however, a dedicated workshop series might be useful.

4 Funding

For AL4MS, we explored the typical funding channels and received funding from CECAM and Psi-k. We had also received a 5k contribution from Aalto University's Science Institute (ASCI) and sponsorship from Advanced Science (Wiley's flagship journal). For the first time, we jointly organized a machine-learning for materials science workshop with the Finnish Center for Artificial Intelligence (FCAI; https://fcai.fi/). FCAI is Finland's AI and machine learning competence center and contributed 5k funding to AL4MS. Through FCAI, AL4MS achieved wider reach to the Finnish machine-learning community.
In the future, machine-learning for materials science workshops could be (partly) funded through a COST action that two of the AL4MS organizers (Rossi and Todorovic) initiated (decision on application still pending). The COST action proposal was a direct outcome of last year's CECAM funded Young Researcher's Workshop on Machine Learning for Materials in Trieste.

5 Will these developments bring societal benefits?

The discovery of new materials for use in catalytic applications, energy storage, diagnostics, and therapeutics is crucial for achieving sustainable and equitable development, as outlined by the UN Sustainable Development Goals (SDGs). All participants agreed on the urgency of the development objectives.
In recent years, there has been a surge in the development and application of machine learning technologies in materials science, yielding promising results across a range of applications. These include the design of sustainable reaction conversion and manufacturing processes, high-performance materials for green energy (such as photovoltaics) and transport (such as lightweight robust metals). While significant strides have been made in algorithm design and theoretical understanding, large-scale real-world applications are only beginning to emerge, leading to the discovery of new stable materials and the design of never-seen-before materials.
AL4MS advanced research in these critical fields by disseminating the latest research advancements to young researchers and fostering collaboration among renowned scientists from diverse fields. By equipping the next generation of scientists with the skills to address complex problems related to high-performance materials design, we aim to further drive progress in these areas.
In the workshop we highlighted the transfer of knowledge from academic research into the industry, promoting technological impact. Industry representatives from Microsoft Research, Toyota Research, and Outokompu provided participants with insights into possible career pathways while offering an overview of the state-of-the-art methods and achievements within industrial R&D. These novel developments are set to boost innovative technologies and create societal impact.

6 Organizers list

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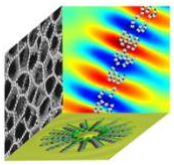

Emerging colloidal dynamics away from equilibrium. Chiral active systems.

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1123
Dates: Mar 1, 2023 - Mar 3, 2023

1 State of the art

Chirality is an intrinsic fundamental property of many natural and artificial systems. Understanding the role of chirality in dynamics of interacting many-body systems is a major challenge. There has been a surge of interest in collective phenomena arising when chirality comes into play in biological [1-4] and artificial [5-9] systems. Microsystems driven out-of-equilibrium by external torques [10-15] are ideal model systems to investigate these phenomena since they avoid the inherent complexity of biological active matter [16]. Spinning particles dispersed in a fluid represent a special class of artificial active systems that inject vorticity at the microscopic level [17,18]. Dense collections of interacting spinning particles represent a chiral fluid [19], which breaks parity and time-reversal symmetries, and displays a novel viscosity feature called the odd viscosity [20,21]. The odd viscosity has been identified in interacting chiral spinners [19], and it led to remarkable effects such as the production of flow perpendicular to the pressure [21], topological waves [22], or the emergence of edge currents [19]. There has been an increasing effort to investigate collective phenomena in systems with chiral active units. Synchronized self-assembled magnetic spinners at the liquid interface revealed structural transitions from liquid to nearly crystalline states and demonstrated reconfigurability coupled to a self-healing behavior [23].
Developing an understanding of complex dynamics in chiral systems driven out-of-equilibrium by external fields represents a significant theoretical and computational challenge. The microscopic mechanisms leading to the dynamic self-assembly and their relations to the emergent behavior in chiral fluids often remain unclear. Computer simulations are often the only method to theoretically investigate such questions; however, modeling the nonequilibrium dynamics presents a huge computational challenge due to the complex many-body interactions and collective dynamics on different time scales. This workshop was aimed at bringing together experimentalists and theoreticians to focus on bridging the gaps between the computational approaches on different levels of coarse-graining in chiral active systems. The goal was to discuss the effects of chirality in a wide class of driven/active systems and to outline the computational approaches that would lead to understanding the complex behavior of chiral active fluids.

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2 Major outcomes

During this 3-day workshop, we discussed the main open problems in the field, recent (often unpublished) developments, and future avenues that could be taken to better understand the complex dynamic behavior of active chiral fluids. The talks and discussions were balanced such that theory, computational approaches, and experiments were discussed within each session resulting in continuous interactions between theoreticians and experimentalists. At the end of each day, we organized round-table discussions to identify challenges (both, experimental and computational) and suggest possible approaches to advance the field. These informal discussions have been highly appreciated by all participants and led to efficient exchanges of ideas and resulted in collaborative opportunities. We generally agreed that the community is characterized by the focus on fundamental physical principles and by the originality of research. In this workshop, the main focus was on the role of chirality and how it governs the collective behavior of out-of-equilibrium (dissipative) ensembles driven by external energy sources. We find that there was also a strong focus on hydrodynamics and the computational methods to model it. Presentations on those topics demonstrated great recent advances in the field and formed an expectation that in the following few years a real breakthrough might be achieved, especially in developing an understanding of dynamic response in systems with non-reciprocal interactions and realization of controls of chiral systems with activity modulations to access novel dynamic states.

Possible new areas

We identify several promising directions in the field of out-of-equilibrium colloidal dynamics.

Role of confinement in collective dynamics of the chiral system. The interplay of activity, chirality, and confinement. Role of elastic boundaries on collective dynamics of active collectives.

Use of non-Newtonian fluid to investigate the effect of memory on the system behavior. In most recent experiments/simulation studies, chiral spinners were investigated in simple Newtonian fluids like water. Adding viscoelasticity, for example by introducing liquid crystalline (LC) media would give rise to complex interparticle interactions leading to novel collective phases away from equilibrium.

Effects of individual particle "memory" on the collective dynamics in active colloidal ensembles. Activity modulations may often access the regimes of active unit motion with partial memory of its previous dynamic states.
Finally, the effect of long-range fluid-mediated hydrodynamic interactions between actively spinning units (spinners, circle swimmers) will continue to be at the forefront of the investigations both experimentally and computationally.
It is expected that research on these topics will grow significantly in the future.

3 Community needs

This workshop is a continuation of an ongoing series focused on a rapidly developing field of emergent colloidal dynamics away from equilibrium. We strongly believe that there is a need for continuing this series. Throughout all previous workshops, we always achieved dynamic discussions and an efficient mixture of computational, theoretical, and experimental presentations. Many fruitful discussions have sparked novel ideas, some of which have evolved into substantive research projects, sometimes through collaborations among the workshop participants. This workshop series was one of the first to provide a discussion platform for researchers in the field of active and driven colloidal materials that are not related to biological systems. The subject of emergent dynamics in complex colloids remains a very active and vibrant area of research, yielding exciting new results and often whole novel directions every year. Such rapid development of the field may sometimes result in fragmentation of the community. Hosting a CECAM workshop every two years serves as a crucial gathering point for the burgeoning community of researchers in this field.

4 Funding

All the topics that have been touched by our workshop are suitable to be funded by the Horizon 2020 program and its follow-up programs. Indeed, some participants have already benefited from this type of grants (ERC starting grant, consolidator or synergy). Moreover, some initiatives have been already undertaken, for example, an ITN network “NANOTRANS” on the transport of soft matter at the nanoscale, a FET cooperation “NANOPHLOW” on similar topics, etc. We have suggested that another collaborative proposal on Emergent Phenomena in chiral active systems could be placed together, either as a training network (ITN) or as a research collaboration (FET).

5 Will these developments bring societal benefits?

The research topic covered by this workshop is, in general, important for the society. Materials that can assemble and disassemble on command, and are capable of self-repair will revolutionize the world. Chirality is an intrinsic fundamental property of many natural systems, and it is expected to be related to the origin of life itself. This workshop focused on microscopic chiral systems and understanding the role of chirality in these systems is of fundamental importance. On the application side, the non-equilibrium flow generated by a spinning, chiral particle, can be explored as a means to stir and mix fluids in microfluidics devices. Colloidal inclusions in a microfluidic system may be used to stop the flow, produce a pressure field, or act as valves to regulate the mixing of streams of fluids. Such methods have a potential to vastly improve the current characterization capabilities (macromolecular analysis, microelectronics, etc.) based on microfluidics. On a larger scale, understanding out-of-equilibrium transport of colloidal particles in complex environments is key to improving drug delivery methods, and designing new products in cosmetics or food production. Larger companies that are proven to be interested in our topics are for example Unilever, Saint Gobain, BASF, Solvay... Funding through the industry contacts can best be organized case-by-case for specific projects of joint interest.

6 Participant list

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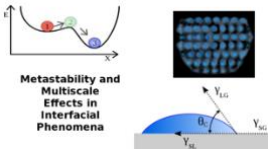

Metastability and multiscale effects in interfacial phenomena

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/38
Dates: Mar 13, 2023 - Mar 15, 2023

1. What were the major topics discussed in the event, and how have they contributed to advancing the state of the art?

Transitions between metastable states separated by energy barriers are key to many processes of practical interest in chemistry, engineering, materials science and physics. First-order phase transitions between solid, liquid and gaseous states are amongst the most

obvious examples and are critical in such wide-ranging phenomena as the production of pharmaceuticals [1,2], the function of the malaria parasite [3], and cloud and polar cap formation [4,5]. The wetting of both smooth and textured surfaces, the diffusion of adatoms on surfaces and the role of bubble cavitation in damage to marine propellers [6] are just a few of the engineering applications. The common thread running through these diverse problems is their multiscale nature which creates unique challenges for experiment, simulation and theory. Experimentally, the early stages of these processes - nucleation, wetting, etc. - typically occur at the nanoscale and isolating them is difficult. Recent advances such as the use of cryo-TEM in ref. [2] are beginning to give insight at this fundamental level. In contrast, atomistic and ab initio simulations give direct insight to the nanoscale but the problem for them is that the system sizes and timescales are small, compared to experimental (macroscopic) conditions. This is the case for instance with chemical reactions (typically involving a transition from a higher to a lower energy state separated by a barrier) and associated calculation of the pathways and rates. To overcome these limitations, a collection of rare-event techniques have been developed over the last 25 years such as the nudged elastic band and string methods among others to study such transitions. At the same time, attention in individual applications has focused on issues such as the definition of unbiased collective variables. Theoretically, the challenge has been that mesoscale approaches (such as the Landau theory of phase transitions) lack molecular-level detail while microscopic tools like classical density functional theory have not been sufficiently robust. However, recent advances in the latter now allow for the molecular-level description of highly inhomogeneous systems, such as wetting of heterogeneous substrates [7] so that, in combination with other frameworks such as fluctuating hydrodynamics, a complete microscopic theory, e.g. of crystal nucleation, is feasible [8].

2. What were the primary outcomes of this workshop, including limitations and open questions?

Several questions arose in the final discussions. One of the most prominent issues was that of the accuracy of existing simulation and analytic methods:
- do different methods give the same results?
- can "blind challenges" be formulated to better test methods.
- can benchmarks be formulated for which theory and experiment are both possible (e.g. colloidal systems)?
- what is the effect of coarse-graining?
- can we estimate errors of existing methods?

In the field of nucleation, the application of existing and future methods to heterogeneous (rather than the more common case of homogeneous) nucleation should receive more attention.
It was also proposed that a bridge between the density field that underlies cDFT and local order (as often investigated in simulations) should be formulated.
As for simulations, there continue to be questions concerning the effects of different thermostats (e.g. that they may bias simulation results) and of system size on the final results.

3. What was the take-home message for the participants?

Over all, the most universal issue seemed to be a desire to move beyond academic and "proof-of-concept" work towards more quantitative and physically relevant applications supported by benchmarks and estimates of errors (e.g. of rates). Also, the importance of comparing results from different methods for consistency was highlighted.

4. Does the outcome(s) of the workshop hold potential for societal benefits?

Metastability is a general concept that finds practical realization in processes such as crystallization, protein folding and chemical reactions, to name only a few. Each of these is fundamental to applications. For example, crystallization is a key step in many industrial processes, in particular in the production of pharmaceuticals while protein folding is key to understanding the pathway from the sequences of amino acids in DNA to the resulting biological function. This workshop focussed on the state of the art in modeling, analyzing and controling these processes. The ability to reliably and accurately predict nucleation pathways and rates, chemical reaction rates, etc. will be of widespread benefit in improving all of these applications.

5. Are there tangible outcomes of the workshop (e.g., publications, new collaborations, plans for proposal submission, software developments, etc.)?

Metastability is a key concept in a vast variety of applications in physics and biophysics, chemistry and materials science. It plays a central role in the description of processes such as crystallization, wetting, protein folding, chemical reactions and liquid-liquid phase separation in biological cells. Potential applications are to the production of pharmaceuticals (which relies on crystallization), climate change (formation of droplets in the atmosphere) and super-hydrophobic materials. In all of these cases, engineering the desired properties and/or outcomes depends on understanding and controlling the process of transition between metastable and stable states. While much of the research, particularly on the methods of mathematically modeling these transitions, is found in the technical physics and mathematics literature, the wide-spread practical importance and applicability of those methods suggests that funding should be sought more widely by linking basic research into such methods to applications.

6. What measures did you take to promote inclusivity (gender, geographical provenance of participants and speakers, career stage, disabilities, etc.)?

The only criteria for inviting participants was that they be active researchers in the relevant fields. This resulted in numerous female and minority participants. We particularly tried to help a young, female Ph.D. candidate from Russia attend although in the end this did not prove possible. We note that our ability to affect the distribution of speakers (by gender, geographical provenance or other criteria) was severely hampered by the fact that the conference took place immediately after the covid pandemic and we had many refusals by potential participants who had previously expressed interest in attending the conference (when originally planned, pre-pandemic).

7. Participant list

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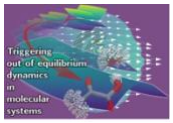

Triggering out-of-equilibrium dynamics in molecular systems

Location: CECAM-HQ-EPFL, Lausanne, Switzerland & online (hybrid format)
Webpage : https://www.cecam.org/workshop-details/1118
Dates: Mar 28, 2023 - Mar 31, 2023

1 State of the art

Describing the out-of-equilibrium dynamics of molecular systems with numerical simulations is a challenging task, whether it happens in the gas phase or in the condensed phase. While the quantum-mechanical evolution equations are essentially known, they can be employed to describe the dynamics of systems of “experimental complexity” only by invoking approximations [1-8], which make them treatable on a computer. Phenomena initiated or driven by different light sources [9-15] are in particular nowadays of interest for potential applications in the control of chemical reactions, or in domains such as energy conversion and phase transitions. High-energy charged particles interacting with solids [16] or biological matter [17] are capable of inducing strong non-equilibrium responses and damages in the target systems. Exciton formation followed by charge recombination and photoluminescence [18] or charge separation [19, 20] for the production of electric current are also currently of major interest for the development of organic electronic devices. Those phenomena happen at the frontier between physics and chemistry, and as a result a complete understanding of their microscopic details requires an intense knowledge exchange between the communities. In addition, the complexity of the developed equations requires a strong support from mathematics and computer-science experts to facilitate the development of efficient theoretical and computational tools for the simulations [21, 22]. The purpose of this alternative workshop was not to discuss applications *per se*, but rather to focus on how theory and

simulations can achieve a realistic description of the fundamental physics underlying out-of-equilibrium (quantum) dynamics in complex molecular systems. The workshop brought together the participants with a broad variety of expertise and background, willing to share their knowledge and recent developments and participate in open and constructive discussions to advance the field.

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2 Major outcomes

The workshop brought up a wide variety of topics and new ideas related to different aspects of non-equilibrium dynamics - from gas-phase molecules to condensed matter and extended systems, using methods ranging from mixed-quantum classical and semiclassical to fully quantum description. Following a set of presentations demonstrating new developments and the remaining research difficulties, the workshop defined grand challenges in the field: simulating long timescales, theoretical descriptions of solvation (or more generally, interactions with a complex environment), light-matter interactions including emission, electron-impact dynamics, coupling to electronic continuum, laser pulse shapes including strong fields, and initial conditions for excited-state dynamics. Some of these topics and corresponding challenges were discussed in more detail during the workshop (long timescales, solvation, electron impact, initial conditions), while others emerged during our extensive discussions. In any case, most challenges remain rather poorly explored and deserve investing future efforts to develop new theoretical frameworks.

The joint discussions brought up questions about open data and data reproducibility. The first can be achieved by creating public repositories with complete sets of inputs and outputs, while the codes need to be curated, available, and well-documented. Regarding the reproducibility issue, the participants discussed the lack of standards in the field. This discussion led to the emergence of a strong initiative for creating common benchmarks and open databases (e.g., for nonadiabatic dynamics methods), as it was done in other research areas such as electronic structure, spectroscopy, solid-state physics, or computational microkinetic. The need for common benchmarks partially comes from the suspicion that researchers tend to show only successful results to promote new developments in theory. On the other hand, it was argued that benchmarks do not push us enough beyond our comfort zone and that focus should also be put on predictions where results are not a priori known, e.g., as a competition between groups to predict experiments without previously knowing the results. Participants agreed to explore both directions, i.e., to define common benchmark systems and to move towards competitive research challenges that potentially go beyond reproducing known experiments. See 'Community needs' below for examples of major initiatives emerging from this workshop.

3 Community needs

There was general consent among the participants that our community needs a workshop dedicated solely to defining common benchmark systems for nonadiabatic dynamics. A follow-up initiative should be taken seriously since previous efforts have had only limited success, mainly because of the complex questions related to benchmarking different families of dynamics methods. A group of ECRs who participated in this CECAM workshop have prepared and submitted an application for a CECAM workshop (last call in July 2023) with an alternative format event dedicated to creating common benchmark sets for nonadiabatic methods. The preferable outcome will be an authoritative scientific publication for the community.

Another group of ECRs from the workshop is currently developing an open-access, web-based tool containing a wide variety of information relevant to the computational dynamics community. The web platform will contain a comprehensive list of different methods (including documentation, examples, and tutorials), an interactive forum for researchers to ask/respond to questions, a standardized database including benchmarks and tests (which could be connected to the outcomes of the proposed CECAM workshop discussed above), relevant announcements, etc. The overall aim is to increase transparency and collaboration between groups. The help and support from CECAM to host this website would be highly valuable.

Another initiative, triggered by Todd Martínez, was to create a prediction challenge in photochemistry. As stated above, numerous methods and strategies for nonadiabatic dynamics exist and have been used to simulate the photochemistry of molecules. However, one can question whether these simulations have been unambiguously predictive. New ultrafast diffraction experiments have recently become available and provide both spatio and temporal resolution on the atomic scale, i.e., molecular movies. This provides a novel opportunity – a double-blind test of the accuracy of excited state simulations. A subgroup of the workshop participants, led by Todd Martínez, has arranged for such a test and challenged the community to predict the results of the experiment – the photochemistry of cyclobutanone studied with UED – and prepare manuscripts for submission to a special issue in The Journal of Chemical Physics. To be considered, submissions must be received before the experimental results are revealed (no earlier than January 2024), and they must include direct predictions of the key experimental observables. The special issue has been announced on the Journal of Chemical Physics website. The crucial role played by our CECAM workshop in triggering this challenge will be clearly identified in the Editorials of the Special Issue.

4 Funding

The different initiatives discussed above are likely to trigger new ideas for future funding opportunities. The prediction challenge will highlight the key deficiencies in simulating nonadiabatic processes and will be based on an actual molecular process and not model systems. As such, multidisciplinary research programs – theory and experiment or different branches of theoretical chemistry/physics (e.g., nuclear dynamics and electronic structure) are likely to emerge from the results of the grand challenge. The two other initiatives will reinforce the community, and creating a series of benchmark systems will require time and effort investment from the PIs involved. All these projects are directly aligned with a very recently funded EPSRC Programme Grant entitled A Universal Approach for Solving Real-World Problems Using Quantum Dynamics: Coherent States for Molecular Simulations (COSMOS), which aims at building a multipurpose code for quantum molecular dynamics, comprising different strategies to simulate experimental observables. The connections between COSMOS, led by Graham Worth, and CECAM are clear. They will lead to the organization of CECAM workshops and schools pushing the different initiatives highlighted in this report.

5 Will these developments bring societal benefits?

The workshop itself was focused on basic science research, prioritizing the theoretical method developments rather than real-life applications with immediate impact on society. However, it is without question that many developments related to non-equilibrium dynamics may potentially have their use for a wide variety of active and emerging societal issues (e.g., development of new materials with optimized optoelectronic properties, harvesting energy from sunlight, atmospheric photochemistry, astrochemistry, medicinal photosensitization, nanotechnology, nanobiotechnology, etc.) A CECAM workshop that will be organized in March 2024 will aim at connecting the field of nonadiabatic dynamics to (experimental) atmospheric chemistry to better predict the interaction of sunlight with volatile organic compounds from the troposphere. Such initiatives will support the uptake of excited-state dynamics methods to the wider community with direct social benefit – in the case of atmospheric chemistry, by improving the quality of atmospheric models predicting the composition of our atmosphere and predicting the formation of secondary pollutants. Some participants also emphasized how we should take the market needs seriously (Prof. Petr Slavicek) and presented some examples from their own research (e.g., predictions of redox potentials). As another example, the idea of an ab initio nanoreactor, a computational tool for automated and accelerated reaction discovery that was presented by Prof. Todd Martínez could potentially be used in different industries (e.g., in oil and gas industry). Industries could also be a source of funds for such developments.

6 Participant list

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Multiscale simulations of DNA from electrons to nucleosomes: 22 years of the Ascona B-DNA Consortium

Location: Congressi Stefano Franscini (CSF), Monte Verità, Ascona, Switzerland
Webpage : https://www.cecam.org/workshop-details/1127
Dates: Apr 16, 2023 - Apr 21, 2023

1 State of the art

DNA carries the genetic information an organism needs to develop, live and reproduce, so that processes such as DNA transcription and replication are central to biology. However, DNA is an extremely long, and flexible, and structurally polymorphic molecule. Consequently, its detailed description is challenging due to its intrinsic multi-scale nature. Its multi-resolution, high complexity requires modelling in an extremely wide range of sizes and time scales. The last several years have witnessed the development of a wide repertoire of theoretical methods aimed to reproduce the properties of DNA, either in isolation or protein-bound [1]. These methods allow researchers to consider DNA at different resolution levels and provide valuable knowledge of its structure, dynamics, and interactions. Recently, this knowledge has broadened to encompass the idea that the detailed chemistry of the four canonical bases along with their epigenetic modifications, also provide a sequence-dependent modulation of the physical properties of the DNA, such as non-zero intrinsic curvature, varying intrinsic twist, and variations in stiffness, and that these sequence-dependent variations of the physical properties of the DNA are key to the control and regulation of the biological processes involving DNA. At a local scale, conformational changes in DNA are mediated by a complex choreography of backbone rearrangements that lead to local and global changes in the helix geometry [2,3] impacting the ability of the DNA to recognize ligands [4], and consequently affecting its functionality. Binding-induced conformational changes in DNA are required for function and are expected to follow the sequence-dependent intrinsic deformation modes of DNA, i.e., are implicitly coded in the spontaneous deformability of isolated DNA. Understanding the sequence-dependent physical properties of DNA then becomes crucial to rationalizing how ligands and, most notably nucleosomes, recognize and modulate DNA activity, i.e., the structural basis of gene regulation.

The ABC 2023 conference was a venue to discuss subjects surrounding the sequence-dependent physical properties of DNA, new methods and new models, with a multiscale perspective. From the shorter atomistic scale to more biologically pertinent length scales (mesoscale), i.e. from electrons to nucleosomes. Top international researchers, ABC members, and collaborators from diverse fields (experimentalists, computational chemists/physicists, and developers of new methods) converged to discuss i) All-atom force field development for nucleic acids; ii) Sequence-dependent mechanical properties of DNA; iii) Coarse-grained models of nucleic acids; iv) Multiscale simulations of nucleic acids; v) Protein-DNA interactions; vi) DNA-solvent interactions; vii) Nucleosome structure and chromatin fibers; viii) Nucleosome positioning; and ix) Epigenetic modifications: DNA and histone tails.

Key References

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2 Major outcomes

The conference held in Ascona in April 2023 was a perfect moment to bring the ABC partners and related colleagues to the place where the consortium was created 22 years before. Three keynote speakers, 39 oral presentations and two poster sessions allowed us to share the latest theoretical and experimental advances on the effects of DNA sequence on its structure, dynamics, and interactions with both the solvent and the proteins involved with chromatin organization (https://danslab.xyz/abc2023).
Pushing the conformational analysis of B-DNA mechanical properties towards next-to-nearest neighbors implies the systematic study of 2,080 unique hexanucleotides. An ongoing project is hexABC (https://mmb.irbbarcelona.org/webdev/slim/ABC/public), where 950 20-mers are being simulated in the sub-millisecond timescale with state-of-the-art force fields. This latest initiative of the ABC consortium was discussed during the meeting and was a perfect time to plan new actions.

3 Community needs

In 2001, during a conference on *Atomistic to Continuum Models for Long Molecules* held in Ascona (Switzerland), the Ascona B-DNA Consortium (ABC) initiative was born from the joint effort of nine independent laboratories (Beveridge *et al*. 2012) around two topics: i) molecular dynamics, ii) sequence-dependent effects in DNA. Now and then, the objective of the ABC has been to produce state-of-the-art molecular dynamics simulations of DNA, develop standards and simulation protocols, and obtain information for the comprehensive study and improved understanding of sequence effects on structure, dynamics, and binding properties.
The collaboration was fruitful, highlighting in 2004 the sequence effects produced by the nearest neighbors (NN) of the d(CpG) step (Beveridge *et al*. 2004), so-called phase I in which 15 ns-long trajectories of ten 15-mer DNA sequences were simulated using the parm94 force field (Cornell *et al*. 1995). From 2007 to 2009, after the release of improved force fields (Pérez *et al*. 2007; Svozil *et al*. 2008), the same library was rerun, now simulating 39 15-mer DNA sequences for 50 ns using the parmbsc0 force field (Pérez *et al*. 2007). For the first time, a systematic structural study was conducted to describe all 136 unique tetranucleotide sequences, the so-called phase II *(*Lavery *et al*. 2010).
Knowing that the length of the simulations was a major concern, a new ABC round (2010-2014) termed µABC was conducted where the microsecond timescale was reached (Pasi *et al.* 2014). The library consisted of 39 B-DNA 18-mers, where all unique 136 tetranucleotides

were repeated more than once, enabling convergence tests. Again, the ABC results prompted the development of an improved force field, the version named parmbsc1 (Ivani *et al*. 2016). Using parmbsc1 and a minimum library of B-DNA sequences termed miniABC (13 ´ 18-mers), all tetranucleotides were analyzed under different conditions, making possible a comprehensive extension of the Calladine–Dickerson rules (Dans *et al.* 2019; da Rosa *et al.* 2021).
Now the hexABC initiative is ongoing, thanks to the joint effort of thirteen groups (the most visible ones) from Europe, the US and South America. The study is focused on the systematic characterization of the physical properties of all 2080 unique hexanucleotides, from a collection of 950, 10μs-long MD simulations. The vast simulation effort will allow the exploration of long-term dynamics of solvated duplexes to define potential frustration effects in DNA, sequence-dependent solvent and ion atmosphere, correlation and signal transfer effects, which could not be explored in previous calculations focused on much shorter elements.
All the research, calculations, and computation time were always done using the available funding from each of the members. ABC has never received any specific funding from its conception. Some of the important meetings that kept alive the community were funded by CECAM and hosted in Lausanne. The community has an increased need to access computational HPC resources and also to organize regular meetings to keep everyone close. A CECAM workshop in the next 2 years would be a great support for the ABC consortium.

4 Funding

We believe that our congress held in Ascona was the first joint CECAM- CSF (Congressi Stephano Franscini) funded meeting. The support of both institutions was essential. Without this combination, it would have been impossible to bring together more than 70 of the world's leading researchers in DNA structure and dynamics. CECAM and CSF should consider joining forces through specific joint calls to repeat this exciting and successful experience.
The ABC goals are still alive through our latest effort named hexABC. The meeting was a perfect moment to plan new consortium actions.

5 Will these developments bring societal benefits?

The ABC consortium and its partners are researchers devoted to basic science. Some of us develop molecular mechanical force fields that could eventually be used by the pharmacological industry to search for new drugs. The basic knowledge generated around the chromatin organization could eventually have an impact on gene regulation or CRISPR applications. The relation between basic and applied science is sometimes not easy to devise. Some talks were centered on aptamers, short oligonucleotides that have multiple biomedical uses. The role of i-motifs in the genome organization was also discussed. Some talks were devoted to circular DNAs at the molecular levels in the context of certain diseases.

Most of the ABC participants are mainly theoretical researchers. The methods applied and developed use computers and HPC resources. Our results are obtained through computer simulations and thus could be considered as green science. This type of theoretical approach to learn and predict real biological processes, at some point in time, will bring societal benefits.

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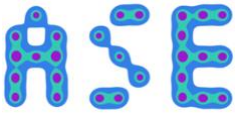

Open Science with the Atomic Simulation Environment

Location: CECAM-UK-DARESBURY
Webpage : https://www.cecam.org/workshop-details/1245
Dates: Apr 24, 2023 - Apr 28, 2023

1 State of the art

Atomistic simulations are widespread in modern chemistry and materials. They can give new insight into experimental data, predict new materials, and screen for desirable properties. These methods encompass a range of modeling approaches, from emerging machine-learning potentials to reference-quality post-Hartree-Fock calculations. They are implemented across an intimidating assortment of software packages making trade-offs in user-friendliness, functionality, interoperability, and ease of automation. It can be difficult to trace the origin of a calculation or ensure that the results used in a study are consistent, and it can be costly to move from one research group to another with an incompatible in-house toolchain. Without shared collaborative tools, high-level algorithms may be implemented in a particular package, leaving the rest of the community to create in-house variants for their own work.
The Atomic Simulation Environment (ASE) is a community-driven Python package that integrates with more than 30 atomistic codes and solves the "n^2 problem" by providing some standard data structures and interfaces to ~100 file formats, acting as useful "glue" for work with multiple packages. New methods such as preconditioned optimizers are written once and immediately available to users of established atomistic codes. Developers of new calculation packages using ASE have been able to focus on novel aspects (e.g., workflow management, machine-learning interatomic potentials, and global structure optimization).
In this workshop, chemistry and physics research were presented that develop and apply atomistic methods with an emphasis on automation, interoperability and reproducibility. The event consisted of a science program with invited and contributed presentations and posters, followed by parallel tutorial and "code sprint" sessions.

Key References

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2 Major outcomes

Workshop participants ranged from ASE founders to active developers to those with no ASE experience. Atomistic codes were featured covering methods including classical interatomic potentials; machine-learned potentials; plane-wave density-functional theory (DFT); linear-

scaling DFT. While plane-wave DFT is a prominent workhorse, it is clear that this community is not overly attached to one Hamiltonian calculator and there is much work to discuss that crosses interfaces between packages. To encourage networking within and across code silos, we provided stickers for attendees to wear, representing codes they are familiar with or keen to discuss: 88 stickers were taken, covering 24 software packages.
Data providence and reproducibility were considered at a few levels: workflow management with Atomic Simulation Recipes and Aiida, forcefield reference methods and comparison in OpenKIM, and reimplementation of published methods in AGOX. Higher-level motivation and considerations for Open Science practices were delivered by representatives of Open Life Science and the Alan Turing Institute. In the tutorial session some examples featured a machine-learning potential drawn from publication Supplementary Information.
Several speakers presented innovations in structure optimization: the AGOX package, GOFEE and Ghost-BEACON methods for global structure optimization and an innovative method for avoiding time-consuming over-converged local optimization steps.
A new set of tutorials was created by the workshop organizers, using Software Carpentry principles and web templates: they remain available at https://ase-workshop-2023.github.io/tutorial/ and represent a gentler, more structured entry-point for novices than the existing ASE documentation and tutorials. A “traffic light” sticky-note system was used to moderate the pace of delivery relative to attendee progress. Contributors engaged with the tutorial component of the workshop: the AbTEM package was presented as a research talk in the science program with a complementary tutorial in the hands-on sessions, while the research talks on OpenKIM and KLIFF included substantial “live-coding” demonstrations. Three of the invited speakers participated in the majority of the hands-on tutorial sessions.
One talk addressed computer graphics, including visualization tools and interoperability with unexpected formats such as 3D-printing. During the discussion session contributors raised the practical importance of plotting and visual outputs; these are an important and often time-consuming part of scientific work but not currently given much emphasis in ASE documentation or tutorial material.
Several code developments took place as a result of the workshop: during planning and development of the core tutorials, bugs were identified, and code merged into ASE to fix issues with MOPAC and Quantum Espresso interfaces. At least 7 other “Issues” and “Merge Requests” were created at the workshop, including a new plugin system for visualization, refactoring of geometry optimizers, improved Windows testing and investigation of some scaling issues in one optimization algorithm.

3 Community needs

To assess community needs the workshop included a discussion session centered around three questions: i) is this community getting better at Open Science; ii) is ASE helping; and iii) what would we like to see next in the ASE ecosystem?
There was a general consensus that whilst Open Science is important, there still remain significant hurdles to its practice. As one participant put it, “there are more ways to do non-open science than open science”. Data files and scripts are increasingly shared, but this is rarely sufficient for full reproducibility. Even in established large facilities (e.g., ISIS) there are challenges in sharing data and best practice is not always implemented. This demonstrates a need for further training and resources targeted at the practice of Open Science within the context of computational materials science.
Participants emphasized that ASE is accelerating Open Science practices by lowering the barriers between silos of individual research groups or institutions. Participants highlighted a number of desirable “Next Steps”: improved visualization tools, reduced computational overheads for MD, better documentation of advanced functionality or “hidden” features within ASE, and better discovery of post-processing features in the form of a “picture gallery”. A thread running through the discussion was the prospect of a compelling “data-to-paper pipeline” that would attract new users.

Active developers pointed out that not all of these things need to live in the core ASE package or be maintained as part of it - but then the challenge becomes signposting across that wider software ecosystem.
To enable development and maintenance of these tools, resources are needed to support the largely volunteer community that contributes to ASE. There has been some success already in bringing together developers and new contributors through “hackathons”, as part of science workshops or as standalone events.

4 Funding

Some publicly funded programs exist to provide training and promote Open Science practices. One invited speaker publicized the OLS mentorship and training program https://openlifesci.org/.
ASE does not have direct project funding or an official project board; development comes as a by-product of other research projects. This leaves a shortfall in man-hours for unglamorous maintenance work; currently this is effectively funded within a NOMAD CoE project to deliver “exascale high-throughput workflows”.
Research software funding tends to come from new projects delivering new features, yet above we identify needs for maintenance, training and “polish”. A 2021 funding call for “Software for Research Communities” by EPSRC (UK) was unusual: it explicitly looked to “adapt or maintain existing software”. This £4.5M call was very competitive and <10% of applications were funded.

5 Will these developments bring societal benefits?

Atomistic simulations play a part in a wide variety of active research programs from drug discovery to the development of new materials for batteries, energy generation (photovoltaic or thermoelectric) and catalysts to reduce energy consumption in industrial chemistry. They provide insight into the behavior of exotic and dangerous systems from crystal phases in planet formation to radiation damage in engineering materials.
A wide variety of simulation packages are used for this: a recent survey Psi-k mailing list members found 64 atomistic codes in use (https://matgenix.com/survey-2022/). To make efficient use of energy-intensive resources it would be best to use the code with the best numerical performance for a given problem; while researchers view this as important, they also prefer to use codes that are familiar and/or easy to use. This survey also found that researchers are not especially satisfied with the quality of post-processing tools provided with those codes. By developing and disseminating good-quality open-source code-agnostic methods and workflows, this community can lower the barrier to adopting new methods and architectures such as machine-learned interatomic potentials and GPU clusters; this will allow researchers to focus on efficiency and novelty.
There is an active discussion around the publication and availability of scientific findings and data. Research funding bodies are generally moving towards more openness so that research outputs are available without cost and with sufficient information to reproduce or build on previous work. This should improve the cost-effectiveness of scientific research and lower the barriers to new entrants. For atomistic calculations this means that data should be available in an interoperable and understandable format, and key tools should not only be available in license-encumbered codes.

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GGMM 2023 - Young Modellers Conference

Location: CECAM-FR-GSO
Webpage : https://www.cecam.org/workshop-details/1221
Dates: May 15, 2023 - May 17, 2023

1 State of the art

Across Europe, different conferences are organized for young modellers like the MGMS Young Modellers Forum in UK, the Hünfeld workshop in Germany, or the Lindau Nobel meeting but these are only few examples in a large variety of scientific conferences held each year and targeting more established scientists. The CECAM has sponsored in the past years few meetings involving specifically young researchers in 2012, 2014 and 2019.

Since its creation in 1983 by Joël Janin, Evelyne James-Surcouf, and Gérard Pepe, the GGMM (Graphical and Molecular Modelling Group) is organizing a conference every two years in France (https://ggmmfr.wordpress.com/congres/) to highlight the advances made by young French researchers. In 2023, the conference will be held in Toulouse (15-17 May). For this edition, we have broadened the audience to include young modellers from European countries. Thus, the organization was performed by a committee French including 6 French and 2 German researchers.

We have organized the CECAM Young Modeller Conference coupled to the GGMM 2023 conference at Toulouse, 15-17 May 2023 (https://ggmm2023.sciencesconf.org). We proposed 5 exciting topics which, we believe, will expand in the future. So, presenting the states-of-the-art for each topic by renowned scientists will help young modelers to reflect on their research and imagine new avenues for their research in the coming years.

1. Multi-scale modelling: A key molecular forcefield at the cross-road in between different scales is the MARTINI forcefield. The MARTINI forcefield was recently updated to allow modelling a large range of molecules. **Pr. Dr. Siewert-Jan Marrink** (Groningen, Netherland) was invited to present recent advances on the MARTINI force field. **Dr Paulo De Souza** (Lyon, France), the main developer of the newest version of MARTINI was also present.
2. Integrative approaches: MD simulations are now more and more intertwined with experimental results, and it is important to correctly compare and combine the two approaches. With the recent advances in protein structure determination, fluorescence microscopy, and NMR spectroscopy both space and time sampled in these experiments can be compared or complemented with results from multiscale MD simulations. We have invited **Dr. Lucie Delemotte** (Stockholm, Sweden) who is combining MD data with different experimental results to study ion channels.
3. Methodological Developments: Advances in MD simulations are often associated with new technical developments such as GPUs or cloud computing. It is, thus, very important

for young researchers to be aware of the last technological developments which will be commonly used in the future. We have invited **Pr. Jean-Phillip Piquemal** who leads the Laboratory of Theoretical Chemistry developing the Tinker-HP program. The development of the GPU-accelerated code for this program allows using the polarizable force field AMOEBA with an efficiency closer to the ones observed for classical atomistic simulations.

4. Molecular and Drug Design: With the development of Artificial Intelligence for protein structures, it is now clear that such methodology can revolutionize our understanding of biological systems and help developing new drugs. This approach is now also booming to complement or extend MD simulations. We have invited **Dr. Noelia Ferruz** (Barcelona, Spain) based on their recent track record on AI to design new protein structure and function.
5. Molecular Interactions: While it is now possible to model diverse molecular systems using MD simulations, such as proteins, nucleic acids, lipids, and their interactions, there are still molecular systems under studied due to their complexity and the difficulty in simulating them. Carbohydrates are still difficult to model while recent scientific results have shown their importance. So, we would like to invite **Dr. Elisa Fadda** (Maynooth university, Maynooth, Ireland) to present her work on glycan modelling in the context of SARS-COV-2 and beyond.

2 Major outcomes

First, this conference was a huge success as it gathered more 185 participants - a large majority of the attendees were PhD students or postdocs. We were not able to accept all the registrations as we reached the maximum number of seats available. In addition of the French and German Molecular Dynamics (MD) community, we managed to welcome scientists from all over Europe (Poland, UK, Ireland, Italy, Switzerland, Spain, Czech Republic, Finland, Belgium) and beyond (Turkey, Japan).

As discussed in the *State of the Art section*, we proposed 5 diversified scientific topics:

- multi-scale modelling: modelling approaches combining different resolutions (QM, AT, CG, and beyond) applied on biological systems (protein, lipids nucleic acids, ..) and their interactions.
- integrative approaches: approaches coupling modelling with data from bioinformatics (co-evolution, seq. alignments, ...) or from experiments (structural biology, biophysics, ...).
- methodological developments: Methodological developments to complete or go beyond MD simulations with a special interest to graphics, AI, and tools developments.
- molecular and drug design: Modelling approaches for the design of proteins (enzymes, ..) or small molecules, drug discovery and screening.
- molecular interactions: Modelling biological complexes: protein-protein, protein-ligands, nucleic acids, sugars, ...

For each topic we had to select six talks among a list of > 90 abstracts. We have created a scientific committee of ten scientists to help to choose the talks (https://ggmm2023.sciencesconf.org/resource/page/id/3). The abstracts which were not selected for a talk were presented during two poster sessions (15th of May and 16th of May during the evening). All the abstracts are available in the conference booklet: https://ggmm2023.sciencesconf.org/data/ebook_GGMM2023.pdf

We have proposed a round table (16th of May) with representatives from different companies:

- Alain Marty: Scientific director of Carbios (https://www.carbios.com/en/)
- Christophe Boldron: Vice President and Heod of Molecular Architects at Evotec (https://www.evotec.com/en)
- Jean-Philip Piquemal: CSO and co-founder of QuBit Pharmaceuticals (https://www.qubit-pharmaceuticals.com)
- Katia Dekimeche and David Rinaldo: Director and application scientists at Schrödinger (https://www.schrodinger.com)

We were really keen to organize such a round table to also show to young modelling scientists opportunities beyond the academia and how science done in academia can be also applied in other sectors.
The feedbacks from young scientists were very positive - below few examples.
I would like to extend my gratitude for the organizing committee for organizing this very successful GGMM conference",
"*Thanks for everything. The event was informative, engaging, and well-structured, and I enjoyed every moment of it.*",
"*Thank you for organizing such amazing conference. It was truly amazing to meet all the modellers and share our work.*",
" *Thanks so much for organizing this really nice congress, and thanks to all the organizers so we can enjoy the communication, the food and the cheerfully atmosphere.*",
"*It was a great organization! Thank you for all your support before and during the conference. It was truly an unforgettable experience for me.*",
"*Thank you for organizing the GGMM2023 conference in Toulouse. I had a wonderful time and found the event to be highly informative.*",
"*I would like to thank you and the entire organizing committee for arranging such a comprehensive and high-quality scientific congress*", etc.

3 Community needs

The presentations on AI technologies and also about new methodological developments highlighted the need of large computational resources with especially powerful GPUs.
With the advances of exascale computing, more and more computing resources will be available to perform very large simulations to reach the entire modelling of a cell as presented by Pr S. J. Marrink during his talk (see *State of the Art* section). This will require also an adaptation of current MD programs to deal with such huge systems. This is what is currently done for the program Gromacs to deal with systems containing hundreds of millions of particles.
Beyond scientific presentations, after two years of COVID restrictions, the conference also highlighted the need for researchers to gather and discuss. The GGMM conference is organized every two years to help young researchers present their work in a very relaxed and kind atmosphere. With the Young Modeller Conference 2023, this very friendly environment was open this year to numerous young researchers across Europe. We believe that this type of conference would be very valuable on a regular basis (every 2-3 years?) for young scientists to create a network. So, proposing this type of conference in different European countries and including young researchers in the organizing committee would be an interesting option to study to push forward future modelers.
In the case of the GGMM, this conference is organized every two years. So, a possibility would be to propose an additional CECAM funding to the GGMM conference every 2-3 times (i.e., every 4-6 years) to organize a special event to gather the whole European community.

4 Funding

With more than 180 researchers onsite, this was a challenging organization for the local organizers team. The budget was high: (93.4k€) but thanks to a large contribution of the CECAM HQ and GSO node we were able to reach a balanced budget. We also obtained fundings from scientific organizations (LAAS, GDR BiM, INSA, TBI, ANITI, INSA, SFB) and from companies (Qubit Pharmaceuticals, Carbios, OneAngstrom, Schrödinger, Evotec). The total amounts of helps was around 32.4k€. The remain amount was then paid by participants for the registration (61k€). We managed to limit the registrations fees for young scientists (300€) while permanent researchers paid a slightly higher price (450€) and company representatives even a higher price (700€).
For this type of event, we did not discuss additional fundings even if we believe that discussions started during this event may help coordinating projects that may benefit later

CECAM fundings to organize future workshops. As mentioned in the previous section, allocating regular money (every 2-3 years) to organize a conference for young modelers covering different topics important for the CECAM would be interesting.

5 Will these developments bring societal benefits?

Social benefit: We believe that this conference help young scientists from all over Europe to meet and discuss to potentially interact in the future. So, this conference was very useful to help them starting a scientific network. From French young researchers, they had the chance to see presentations and then interact with renowned invited speakers who stayed for the three days of the conference.
Economic benefit: The round table help participants to identify senior researchers in companies and ask questions specific questions during the round table. This may create links between researchers, labs, and companies in the future. The participations of these researchers from companies may also help to diffuse academic methodologies into different companies.

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Young Researchers' School on Theory and Simulation in Electrochemical Conversion Processes

Location: CECAM-FR-MOSER, École Normale Supérieure, Paris, France
Webpage : https://www.cecam.org/workshop-details/1216
Dates: May 23, 2023 - May 26, 2023

1 State of the art

Electrochemical processes are the cornerstone of green chemistry and energy-conversion devices. The accurate modelling of electrocatalytic reactions in the presence of electric fields, in particular, is key to the study of reduction/oxidation processes involved in the synthesis of value-added chemicals, as well as to shedding light on the mechanisms underlying the origin of life (i.e., prebiotic chemistry). The theoretical treatment of electrochemical phenomena is characterized by a high level of complexity. Non-trivial chemistry and electrodynamics are intertwined to form intrinsically multiscale systems, with certain aspects that can be treated only at the atomistic level, while others must be treated as a continuum. From a methodological perspective, the simulation of a system's dynamics at the atomic scale in the presence of applied potentials benefits from a number of advancements that have brought the modelling of electrode-reactants-electrolyte interactions from a fairly quantitative to a strikingly accurate predictive ability. On the one hand, grand-canonical density functional theory (GC-DFT) methods have been extensively used to simulate the quantum properties of electrochemical interfaces and, due to their ab-initio nature, have proven to be particularly suited for the simulation of electrochemical reactions and the rationalization of absorption mechanisms. On the other hand, constant-potential molecular dynamics (MD) methods have been used to model complete electrochemical cells under an applied voltage, paving the way to the atomistic simulation of energy-storage devices. Recent advancements in classical density functional theories (c-DFT) make it possible to compute accurate solvation free-energies of electrochemical interfaces and gain new insights on the thermodynamic stability of electrochemical products and reactants. Finally, the modern theory of polarization and its application to deal with finite electric fields or electric displacement fields have fostered recent advancements in the modelling of metal-electrolyte interactions, allowing for an explicit treatment of the electrolyte while maintaining a quantum-level description of the system. On this front, equivariant and long-range machine-learning methods hold great promise in overcoming the time and length scale limit associated with current ab-initio approaches and predicting the non-local electronic response of the electrochemical interface under applied fields.
The event aims at bringing together a multidisciplinary array of leading experts and young researchers working on the theory and simulation of electrochemical conversion processes. By promoting the discussion of methods and approaches leveraging different philosophies, we expect the workshop to achieve three main objectives:
1) Create a koiné within which method-oriented and application-oriented practitioners can more easily and fruitfully exchange ideas and disseminate cutting-edge achievements. To this end, introductory lectures, a panel discussion and ample time for informal discussion during coffee breaks are foreseen.
2) Offer to young researchers a complete and pedagogical overview of the state-of-the-art in the modelling of electrochemical processes. Towards this objective, the workshop will include: i) introductory lectures to present in detail the theories and computational methods underlying the simulation of electrochemical systems, ii) hands-on tutorials to nurture practical experience in the dedicated codes and software, i.e., constant-potential classical MD (MetalWalls), grand-canonical DFT (Quantum ESPRESSO - ENVIRON), finite-field methods with fixed electric or displacement field calculations (CP2K), iii) coffee breaks and poster sessions to stimulate informal exchanges among junior and experienced researchers.

3) Identify challenging frontier problems which are now accessible thanks to the latest advancements in the field and discuss the criticalities related to pressing technological and environmental problems. To this end, discussion among participants will be promoted by means of multi-thematic invited lectures, time for informal exchanges during coffee breaks and a panel discussion.

2 Major outcomes

The workshop introduced to the audience five state-of-the-art community codes in the field of electrochemistry, with tutorial sessions showcasing specific applications and illustrating actions and requirements inherent to broad case studies. These included: i) MetalWalls, a classical molecular dynamics code dedicated to electrochemical systems; ii) CP2K, with a particular focus on Finite field density functional theory molecular dynamics; iii) GPAW, with a deep-dive on Electrochemical thermodynamics and kinetics with grand canonical ensemble DFT; iv) Quantum Espresso and Quantum Environ, and their use for Electrochemical interfaces simulations; v) tranSIESTA, and the Non-Equilibrium Green's Functions formalism for electrochemical cell simulations.
From the applicative perspective, during the workshop applications of advanced theory and software developments have been discussed in the context of a broad array of domains. These include (but are not limited to): electrified metal-water and oxide-water interfaces, carbon based electrodes and water-carbon interfaces, reactive processes at electrochemical interfaces (e.g., catalytic reactions and corrosion), spectroscopy at aqueous interfaces, electrochemistry in solution (e.g., prebiotic chemistry), transport phenomena in electrolytes.
During the course of the event, possible research trends have emerged. Significant examples are:

- The integration of machine learning approaches to partly by-pass *ab initio* approaches.
- The importance of advancing the state-of-the-art in software engineering to empower researchers with larger-scale modelling via more efficient codes.
- The need to go beyond idealized models to move from qualitative to quantitative agreement with experiments.
- The potential and relevance of models encompassing or interfacing different levels of theory (ab initio+atomistic empirical models+cDFT) at the same time.

Throughout the school, the relevance of cross-fertilization of ideas and know-how to account for the multiple scales involved in the electrochemical problem was also a recurring emergent theme.
The benefit of a tailored event, where technical detail about numerous codes and approaches were discussed in an open and pedagogical manner, was highly appreciated. In the future we foresee the integration of expertise and perspective by also including experimentalist and/or industry representatives, to strengthen the interdisciplinarity of the event and consider novel outstanding challenges.

3 Community needs

The community needs emerged from our workshop and discussion are linked to both capacity and research coordination.
From a capacity standpoint, computational needs inherent to the simulation of large complex atomistic models with a good accuracy may result critical, in particular if only modest computational budgets are available. Computational expenses are quite tasking especially for purely *ab initio* approaches. Computational cost may result moderate in parametrized approaches, which nevertheless may suffer inaccuracies due to the constrained expressivity in the parametric function to evaluate energy, forces, and dipoles. Along these lines, the continuous development of polarizable empirical force fields is a viable strategy toward more and more reliable simulations.

Good software engineering practices and advancement code-developments (e.g., GPU-acceleration) would greatly benefit the community and are very much needed to democratize access to methods and performances.
The integration of advanced machine learning method that are endowed with the same generality of *ab initio* methods, but enable to decrease by one or more orders of magnitude the cost of a calculation, represent a promising methodological advancement to satisfy the need to run realistic complexity in the simulations at an affordable computational cost. The development of these methods is still emergent nevertheless. Machine learning developments are particularly advisable for the construction of surrogate models able to correctly address long-range electrostatic effects.
From a research coordination standpoint, the community benefits from further cross-fertilization of ideas and a focus on the multi-scale nature of electrochemical processes. Structural features at electronic, atomistic, nanoscopic, and microscopic level all affect, e.g., the activity and selectivity of a catalyst. While we hope that this event acted as a stepping stone in building links across different groups and specializations, further steps in this direction are needed. Not many workshops have been organized on the topic of this school this year. The feedback from the invited speakers, contributed speakers, and attendees, suggested a good appreciation for a focused event, with a technical-oriented program. While we do not foresee the immediate need for formally establishing a workshop series, we plan to organize a new edition in May 2025.

4 Funding

The present workshop was funded by CECAM, PSI-K, and ENS-PSL. For future events, we will consider application to Societies in Chemistry, Electrochemistry, and Catalysis. Towards establishing recurring (e.g., bi-annual) schools for young researchers, synergies with these entities could in fact be highly instrumental. Gathering funding from additional sources will further allow to accommodate more young researchers as in-person attendees, which we see as a possible additional need in future events.

5 Will these developments bring societal benefits?

TSECP focuses on advancing research in electrochemistry by disseminating both the theoretical foundations as well as presenting the state-of-the-art and beyond to young researchers. Our primary goal was to train a young generation of scientists with a broad vision and strong technical skill to tackle complex challenges in the theory and simulation of electrochemical processes. In the long-term, we hope that this training and technical capacity-building was beneficial to the professional life of researchers that will work in green energy and chemistry, with an academic, industrial, or policymaking role.
In this regard, the electrification of society will in fact play a key role in transforming our economy while meeting highly desired techno-economic and socio-environmental objectives, such as the UN Sustainable Development Goals (SDGs). The discovery and application of new electrochemical processes could indeed represent a turning point towards CO2 neutrality, closed-loop production on essential platform molecules, and in green energy.
In recent years, numerical methods in the field of electrochemistry made leaps, moving from niche application to almost approaching a realistic complexity in the models that are simulated. These advancements include the design of sustainable conversion reactions, efficient manufacturing processes, and the creation of high-performance materials for green energy solutions like photovoltaics and lightweight, robust metals for transportation.
In the field of theoretical electrochemistry, important milestones have been put forward concerning the theoretical assessment of interfaces in different conditions (constant potential vs constant charge) and their reliable simulation. Although algorithm design and theoretical understanding have made substantial progress, the practical implementation of these approaches on a large scale is still in its early stages. However, it holds the potential to uncover new stable materials and facilitate the design of unprecedented materials.

While the current event did not foresee the participation of industry representatives, we will consider this for next events, to enrich the experience of the audience and facilitate the collaboration between academic experts and industry. Potential partners are emerging European holdings in the manufacturing of fuel cells and other electrochemical devices, e.g., De Nora (IT), Thyssenkrupp Nucera (DE).

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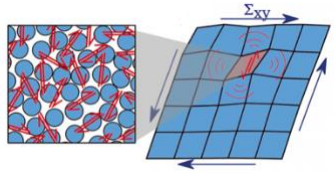

Mesoscale modelling of driven disordered materials: from glasses to active matter

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1206
Dates: May 24, 2023 - May 26, 2023

1 State of the art

Amorphous materials, such as glasses, foams, emulsions, and granular packings, exhibit complex mechanical behavior and rheological properties that have been the focus of extensive research. Recent advancements in understanding the behavior of amorphous solids have shed light on their yielding transitions, rheology, devitrification, and relevance to active and biological systems. Mesoscopic models have played an increased role in this respect. A crucial advantage of this model class lies in the possibility of drastically decreasing the number of freedom, thus making it possible to investigate the size effects and to bridge the gap in multiscale approaches.
The yielding transition of amorphous solids has been extensively studied, revealing the presence of universal behavior in their mechanical response to load. This transition involves an initial elastic regime followed by intermittent bursts of activity known as "avalanches." Works have investigated the effects of temperature on the criticality and rheology of amorphous solids. Elastoplastic models, considering temperature-dependent activation of weak sites, provide valuable insights into the interplay between temperature, driving rate, and finite-size effects on the system's behavior.
Additionally, the fatigue failure of amorphous solids under cyclic shear deformation has been investigated. Elastoplastic modelling has provided insights into local stabilities' role and distribution in determining yielding behavior and fatigue failure. The dependence of the time to failure on the amplitude of applied shear strain has been examined, contributing to understanding fatigue properties in amorphous solids. Whether in monotonic deformation or under cycling, the elastoplastic models are completed via mean-field descriptions taking advantage of an analytic approach.

The rheology of disordered biological systems during deformation processes has also garnered significant attention. Active matter systems, such as self-propelled particulate systems, have been investigated to understand the interplay between self-propulsion and shear stress. Moreover, biological systems, including tissue deformation, e.g., during gastrulation, have been studied to elucidate their active rheology. A common strategy is to employ a vertex model formulation to investigate the active (T1) transitions in tissue layers, providing insights into the catch-bond mechanism and its feedback loop with stress.
The last subject where a coarse-grained approach at the mesoscopic scale is particularly relevant is that of the glass transition. The dynamics of supercooled liquids lend themselves well to the mesoscopic description when it is desirable to describe the facilitation. Devitrification, the transition from a glassy state to a liquid state upon heating, has been studied in ultra stable glasses. Molecular dynamics simulations revealed a two-step devitrification process involving the formation and growth of isolated liquid droplets, followed by the coalescence of these droplets into large domains. This two-step process highlights the nonequilibrium kinetics of glasses, offering a thermodynamic interpretation of the glass transition. The last kind of tool investigates the correlations of tensor field components in isotropic systems. It explores their implications for understanding stress and strain correlations in various scenarios, including equilibrium and driven elastic and viscoelastic bodies. The findings provide insights into the structure and symmetries of isotropic tensor fields, shedding light on the long-range correlations observed in real space and highlighting the role of phenomenological parameters and relaxation dynamics in describing time-dependent correlation functions.
In summary, state of the art in mesoscopic modelling in disordered systems encompasses a wide range of topics, including yielding transition, rheology, temperature effects, supercooled liquids dynamics, devitrification, and fatigue failure. Recent advancements in these areas and the exploration of active matter systems and biological materials have deepened our understanding of the behavior and criticality of amorphous materials. Further research in these areas, guided by studies such as those presented in this workshop (cf. references below), holds promise for advancements in material science, engineering, and our understanding of biological systems.

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2 Major outcomes

This workshop on the mesoscopic description of driven disordered solids provided a platform for researchers to present their latest findings and discuss key themes in the field. The workshop was organized into four sessions that spanned three days, covering a wide range of topics and yielding significant outcomes.

1) Yielding and Rheology. One major outcome of the workshop was the advancement in understanding the yielding behavior and rheology of amorphous solids. The presentations by Korchinski highlighted the effects of temperature on criticality and rheology, shedding light on the interplay between temperature, driving rate, and finite-size effects in amorphous plasticity. These contributions deepened our understanding of the universal behavior and critical exponents of yielding transitions in amorphous materials. Tarjus discussed the challenges posed by finite-size effects in nonequilibrium phase transitions and the importance of mesoscale modelling and effective theories in describing the yielding behavior of amorphous materials. The exploration of effective modelling approaches allows for a more comprehensive understanding of the underlying mechanisms and critical points controlling the behavior of amorphous solids.

2) Fatigue and Failure. One of the workshop's prominent focuses was investigating fatigue failure in amorphous solids under cyclic shear deformation. Sastry presented results from finite element-based elastoplastic modelling, emphasizing the role of the distribution of local stabilities in determining yielding behavior and fatigue failure. The dependence of the time to failure on the amplitude of applied shear strain was explored, providing valuable insights into the fatigue properties of amorphous materials. These findings contribute to understanding the failure mechanisms and structural changes occurring during cyclic loading.

3) Active Matter and Biological Systems. Active matter systems and biological materials have emerged as important areas of study within the field of amorphous solids. The workshop highlighted the relevance of understanding the behavior of active matter and its implications for the mechanical properties of amorphous materials. Active matter, such as self-propelled particulate systems, exhibits unique dynamics and collective behaviors that influence their response to external forces, including shear stress. The study by Henkes on active rheology in biological tissues during processes like gastrulation provided valuable insights into the interplay between cellular activities and mechanical responses. These investigations deepened our understanding of the complex behavior of amorphous materials in biological systems and active matter, paving the way for future research in this interdisciplinary area.

4) Advancements in understanding the slow dynamics of supercooled liquids. The last outcomes of the workshop concern the rigidity of glasses and their relation with supercooled liquids dynamics. Innovative algorithms have been introduced to extract excitations, revealing the impact of local barriers on slowing down dynamics. Molecular dynamics simulations uncover a two-step process for the devitrification of ultra stable glasses, explaining deviations from classical kinetics and the emergence of a length scale. Swap Monte Carlo simulations provide insights into the energy landscape, which suggests Arrhenius dynamics at low temperatures. Advances in understanding slow dynamics near the glass transition and the facilitated trap model have also been discussed. More theoretical approach conducted by Wittmer has explored the correlation functions of tensor fields, highlighting isotropic fourth-order tensor fields and invariant correlation functions. Symmetries and isotropic tensor field structures have explained long-range correlations in real space.

In summary, the workshop showcased the relevance of the coarse-grained statistical mechanics approach in describing disordered systems. In particular, it highlighted the analogies between passive and biological systems and showed the growing significance of active matter systems and biological materials within the field of amorphous solids. Understanding the behavior of amorphous materials in these contexts opens up new avenues for research. It provides insights into the collective dynamics, mechanical properties, and structural changes occurring in these systems. Additionally, exploring cyclic driving and fatigue phenomena enhances our understanding of the long-term mechanical reliability of amorphous solids, aiding in developing improved materials and engineering applications.

3 Community needs

The workshop also provided an opportunity to discuss the research community's current needs in the mesoscopic disordered system field and identify potential future directions for investigation. Several critical areas of interest and community needs were highlighted during the discussions.

One crucial aspect that emerged was the need for improved experimental techniques and characterization methods for studying the behavior of amorphous materials. Developing advanced imaging and spectroscopic techniques with high spatial and temporal resolutions would enable a more detailed understanding of the structural changes, rearrangements, and dynamics occurring within these materials during various mechanical processes. Additionally, integrating experimental data with theoretical and computational models would facilitate a comprehensive understanding of the underlying mechanisms governing the behavior of amorphous solids.

Another community need identified during the workshop was the development of predictive models and simulation techniques that capture the complex and multiscale nature of amorphous materials. Current modelling approaches, such as elastoplastic models and mesoscale simulations, have made significant progress in capturing the behavior of these materials. However, there is a need for more refined and accurate models that can capture the intricate interplay between microscopic dynamics, structural evolution, and macroscopic mechanical responses. Integrating machine learning and data-driven approaches with traditional modelling techniques could lead to more accurate predictions and efficient simulations of amorphous solids.

Collaboration and interdisciplinary research were also emphasized as critical needs within the community. The field of amorphous solids intersects with various disciplines, including materials science, condensed matter physics, statistical mechanics, and biology. Encouraging collaborations between researchers from these diverse backgrounds would foster cross-pollination of ideas, methodologies, and expertise, leading to innovative approaches and breakthroughs in understanding the behavior of amorphous solids.

Lastly, the workshop identified the importance of addressing real-world applications and engineering challenges related to amorphous materials. Understanding the mechanical behavior, failure mechanisms, and reliability of amorphous solids under different loading conditions is crucial for their practical utilization in manufacturing and healthcare industries. Bridging the gap between fundamental research and practical applications would require close collaboration between academia, industry, and policymakers.

In conclusion, the workshop highlighted the community's needs and set the stage for future research directions in the field of mesoscopic disordered systems. Key focus areas were identified as improved experimental techniques, refined modelling approaches, interdisciplinary collaborations, and a focus on practical applications. Addressing these community needs will not only deepen our understanding of amorphous solids but also contribute to advancements in materials science, engineering, and various technological domains.

4 Funding

Our community relies on various funding channels, including European grants such as Horizon 2020 grant (e.g., ERCs and networks) and local grants from each country (e.g., ANR grants in France). Thanks to their shared interest in the subject matter and their commitment to advancing scientific understanding, the workshop participants have been able to discuss future research directions. Combined with the collaborative environment provided by the CECAM infrastructure, it encouraged informal discussions. It facilitated the exploration of potential collaborations and joint research projects even though we have yet to learn of the emergence of a formal collective proposal.

5 Will these developments bring societal benefits?

The advancements and developments in the field of the mesoscopic description of disordered solids hold significant potential for bringing various societal benefits. While the primary focus of research in this field lies in fundamental understanding and technological advancements, the outcomes have the potential to contribute to broader societal needs and challenges. Here, we discuss some potential societal benefits that could arise from the improvement of the modelling of such systems.

Advanced Materials and Engineering: The improved understanding of the mechanical behavior and structural properties of amorphous solids can lead to the development of novel materials with enhanced mechanical strength, durability, and flexibility. These materials could find applications in numerous sectors, including aerospace, automotive, construction, and energy. For instance, lightweight and high-strength amorphous alloys could be used to manufacture fuel-efficient vehicles, while robust and damage-tolerant amorphous materials could be employed in building structures to improve safety and resilience. Amorphous solids have shown promise in various energy-related applications. For example, advancements in understanding amorphous photovoltaic materials could lead to more efficient solar cells, enabling the widespread adoption of renewable energy.

Biomedical Applications: The unique properties of amorphous solids make them attractive for biomedical applications. For instance, bioresorbable amorphous materials could be used to develop temporary implants that gradually dissolve in the body, eliminating the need for additional surgical procedures. Amorphous drug delivery systems could enhance the solubility and bioavailability of pharmaceutical compounds, leading to more effective treatments. Furthermore, advancements in understanding the behavior of proteins could have implications for developing novel drug delivery systems and biomaterials.

Environmental Impact: Developing sustainable and environmentally friendly materials is paramount in addressing global environmental challenges. By optimizing the properties of disordered systems, it is possible to design materials with reduced environmental impact.

It is important to note that realizing these societal benefits requires scientific and technological advancements and collaborative efforts among researchers, industry, policymakers, and the public. Ethical considerations, environmental sustainability, and responsible innovation should guide the translation of research outcomes into practical applications. A better understanding of disordered solids, either passive or active, have the potential to bring significant societal benefits across multiple domains, including advanced materials, energy technologies, biomedical applications, environmental sustainability, and technological innovations. We can strive towards a more sustainable, efficient, and technologically advanced society by harnessing the knowledge gained from research in this field.

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Open Databases Integration for Materials Design

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1208
Dates: Jun 5, 2023 - Jun 9, 2023

1 State of the art

In the last few years, materials design has changed quite dramatically. Thanks to the increase of computing power, large sets of first-principles calculations can be performed automatically, adopting a high-throughput (HT) approach. Large databases (DBs) can then be created with the calculated properties for existing and hypothetical materials. In the same spirit, experimental databases have also developed, gathering different kinds of materials properties. All these DBs can be interrogated for discovering materials with desired properties. Furthermore, machine-learning models can be trained to predict the properties of other materials.
Many such DBs have appeared online (e.g., AFlow, COD, Materials Cloud, Materials Project, NOMAD, and OQMD, etc.). In most cases, a Representational State Transfer (REST) Application Program Interface (API) is available to interrogate the DB through scripts.

However, till recently, it was only possible to query one DB at a time, and the APIs are very different from one DB to another.
Thanks to the OPTIMADE consortium (gathering all the key players involved in these different efforts), a common API was developed [1] through a series of meetings:

- 24-28 October 2016 at the Lorentz Center in Leiden, Netherlands
- 11-15 June 2018 at the CECAM in Lausanne, Switzerland
- 11-14 June 2019 at the CECAM in Lausanne, Switzerland
- 8-12 June 2020, virtual CECAM event
- 7-11 June 2021, virtual CECAM event
- 30 May-3 June 2022 at the CECAM in Lausanne, Switzerland

The OPTIMADE API is flexible and extensible by design, such that it will cover more use cases going forward. The development and adoption of the OPTIMADE API rely on the involvement of a large number of scientists so contributions from the community are strongly encouraged.

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2 Major outcomes

The meeting consisted of both a tutorial and a workshop. There were about 30 online participants to the tutorial as well as 5 others in person. The participants had been asked to watch a series of videos before the actual tutorial. The tutorial thus started by a brief recap of the main points of the videos and then a Q&A session. The latter was quite lively with questions both on line and from the people present in the room. The tutees were then asked to devise a small project involving the use of the OPTIMADE API. They had to work on their own on the topic with a series of Q&A sessions to help them solve the problems that they encountered. Finally, on the third day, they presented a series of elevator pitches about their achievements. Their project gave generated a number of ideas for potential improvements of the API.
On the workshop side, there were four main presentations:

- Noël Jakse described the Diadem PEPR
- Casper Andersen expose the ongoing research at SINTEF
- Luis Fuentes-Cobas introduced the Material Properties Open Database (MPOD)
- Alex Ganose presented the Institute for Digital Molecular Design and Fabrication (DigiFAB) at Imperial College

In all cases, the possible connections with OPTIMADE were highlighted. In the case of MPOD (which was attracted through the outreach of the CECAM-funded OPTIMADE workshop), implementation sessions even took place during the meeting such that it can almost expose the OPTIMADE API (this should be the case in the coming weeks). Furthermore, there were a number of elevator pitches by Rickard Armiento (HTTK and OMDB), Dani Beltrán (BioExcel), Evgeny Blokhin (optimade.science and MPDS), Tara Boland (CMR database), Kristjan Eimre and Jusong Yu (the Materials Cloud), Matthew Evans (optimade python tools and ODBX), Kevin Jose (use case of OPTIMADE), Adam Krajewski (Ultera and other alloys databases), Andrius Merkys (COD and TCOD), Jacob Pietryga (OQMD), Ji Qi (matterverse.ai), Janosh Riebesell (the Materials Project), and Cormac Toher (AFLOW). These elevator pitches showcased the recent advances in the different databases with respect to OPTIMADE.
As usual the workshop included numerous discussions in subgroups followed by plenary sessions in which the different subgroups would report about their advances. One of the key discussions was about the possible to query for partial data. This is really a key feature for molecular dynamics trajectories for which the amount of data is such that one usually indicates

the frames that are requested (e.g., by indicating the first frame, the last frame, and the steps between frames). This was really a complicated issue, but by the end of the conference a pull request was almost ready. This will make it quite easy to finalize the specifications for the trajectory end-point.
Another important discussion was devoted to properties and, in particular, to the specification of units. In this case, the pull request was approved during the workshop. Some discussions took place about the calculations endpoint and about the possibility to have domain specific name spaces (such as _dft) for properties, as well as about workflows (taking advantage of the presence of developers of AiiDA, ASR, atomate, HTTK, and jobflow).
Another subgroup discussion was devoted to magnetic properties and yet another to the extension of the structures specification to include the possibility to describe bonds and, for molecules, to use SMILES, SMARTS, or InchIkeys. Other subgroups discussions were devoted to solving issues in the GitHub repository and some people worked on practical implementation (e.g., OPTIMADE for MPOD and CMR databases). In fact, the workshop was crucial for finalizing changes to the specification ahead of the forthcoming 1.2 release.
Finally, following the first successful paper about OPTIMADE [1], the OPTIMADE consortium was invited by two journals to submit a follow-up paper. During the meeting there was considerable progress on drafting a second paper, which covers improvements to the OPTIMADE API since the first paper (including the trajectories highlighted above), plans for future extensions to the OPTIMADE API (for example those mentioned above), and real-life use cases of the OPTIMADE API that will serve as exemplar templates for scientists in the future. With the draft paper now ready for all members of the consortium to review, and a meeting date set to approve the text, we hope that the text can soon be submitted to a peer review journal. This second paper, once accepted, would be a significant boost for the adoption and profile of the OPTIMADE API.

3 Community needs

Materials design and the broader materials informatics field can greatly benefit from the OPTIMADE API by providing a unified approach to querying multiple materials databases. With the OPTIMADE API, researchers and scientists can use the same query syntax to access data from various databases, eliminating the need to learn and adapt to different interfaces for each database, as showcased at optimade.science. This streamlines the data retrieval process and facilitates cross-database searches, ultimately saving time and effort for materials researchers.
The OPTIMADE API also aligns with the FAIR principles (Findable, Accessible, Interoperable, and Reusable) that are gaining prominence in the materials community. By adhering to these principles, the OPTIMADE initiative contributes to enhancing the discoverability, accessibility, interoperability, and reusability of materials data. It enables researchers to easily find relevant data, access it in a standardized manner, integrate it with other datasets, and reuse it for various purposes, fostering collaboration and advancing materials research.
To ensure the success and continued development of the OPTIMADE initiative, it is crucial to involve and engage important players in the materials community. Collaboration with key stakeholders, such as developers from organizations like ColabFit and MPDD, is essential to encourage adoption and implementation of the OPTIMADE API across different databases. Building a strong and inclusive community that shares a common goal of utilizing the OPTIMADE API will foster collaboration and knowledge exchange, leading to further advancements in materials research and development.
In addition to the immediate benefits of the OPTIMADE API, the community that is forming around this initiative can serve other purposes as well. Discussions have already emerged about using this community as a platform for defining standards and developing an ontology for materials. This indicates the potential for the OPTIMADE initiative to extend beyond API development and become a hub for establishing common standards and best practices in the materials field. Workshops and gatherings that bring together a diverse group of experts can facilitate these discussions, leveraging the collective expertise and influence of the participants to drive the adoption of standards in the broader materials community.

In summary, the materials community recognizes the value of the OPTIMADE API in facilitating materials design and promoting the FAIRification of materials data. Sustaining and expanding the OPTIMADE initiative by involving important stakeholders, fostering a common target, and leveraging the community's potential for standardization efforts will not only enhance data access and interoperability but also drive advancements in materials research, development, and collaboration.

4 Funding

The OPTIMADE consortium has strategically established connections with key players in the materials science community on a global scale, opening up various funding opportunities. At the European Union (EU) level, OPTIMADE has established a link with the European Materials Modeling Council (EMMC). The objectives of the OPTIMADE API align with those of the EMMC, and fruitful interactions have already taken place between the two entities. In fact, several members of the OPTIMADE community actively participate in the boards of the EMMC, indicating a close collaboration. As a result, discussions have been initiated to jointly apply for EU funding calls. For instance, the EMMC is currently benefiting from a Coordination and Support Action, and when a relevant funding call is issued, European members of the OPTIMADE consortium will be involved in preparing and submitting a new proposal, leveraging the expertise and resources of both organizations.
In the United States, OPTIMADE has established communication with the NIST Research Data Framework and the Materials Research Data Alliance (MaRDA). These connections provide opportunities for collaboration and potential funding avenues. By engaging with these influential entities in the U.S., OPTIMADE can tap into funding opportunities related to materials research and data infrastructure projects. This collaboration enables OPTIMADE to strengthen its network, share knowledge, and align its efforts with initiatives in the U.S. materials science community.
Collaborating with organizations like the EMMC, NIST Research Data Framework, and MaRDA not only broadens the reach of OPTIMADE but also enhances its chances of securing funding from diverse sources. The OPTIMADE consortium can actively participate in joint funding applications, leveraging the expertise and resources of its members to strengthen proposals and increase the likelihood of success.
Furthermore, the established links with these key players in the materials science community provide OPTIMADE with valuable opportunities for knowledge exchange and leveraging existing resources. By fostering collaborations and partnerships, OPTIMADE can contribute to the development of a robust materials data ecosystem and establish itself as a vital component of the global materials science community.
In summary, the connections established by the OPTIMADE consortium with prominent entities like the EMMC, NIST Research Data Framework, and MaRDA offer valuable prospects for securing funding. Collaborative efforts with these organizations not only enhance the chances of receiving funding but also enable knowledge sharing, resource utilization, and the development of a strong and interconnected materials data infrastructure.

5 Will these developments bring societal benefits?

The OPTIMADE API holds significant promise in addressing the challenges our society faces, and its advancements in materials design will bring numerous benefits. In the context of the ongoing energetic transition, specific materials with targeted properties are required for various applications such as denser batteries, photovoltaics, thermoelectrics, and catalysts. The OPTIMADE API represents a crucial step forward in this field. By enabling users to query multiple databases using the same query syntax, the API grants access to a wealth of materials knowledge without the need to learn different APIs for each database. This streamlined access to diverse materials data empowers researchers to explore a broader range of materials possibilities and make more informed design decisions.

Moreover, the OPTIMADE API's ability to facilitate the integration of information from multiple databases has significant implications for machine learning methods. By combining data from various sources, researchers can enhance the training and performance of machine learning models, enabling more accurate predictions and accelerating materials discovery and design processes. This integration of data through the OPTIMADE API helps researchers harness the collective knowledge stored in different databases, avoiding redundant calculations and maximizing the utilization of computational resources. This, in turn, allows databases to allocate their resources toward expanding the boundaries of materials knowledge rather than duplicating efforts.
The social benefits of the OPTIMADE API are indirect but substantial. By simplifying the materials design process and expanding the available materials knowledge, the API empowers researchers to develop innovative materials that can address pressing societal needs. The improved design and optimization of materials, such as more efficient batteries or advanced catalysts, have direct implications for areas like renewable energy, sustainable technologies, and environmental preservation. By contributing to the development of materials that provide tangible benefits to society, the OPTIMADE API indirectly supports the advancement of various industries and the overall well-being of individuals.
In summary, the OPTIMADE API's impact on materials design and its ability to streamline access to materials data have significant societal benefits. The API enables researchers to tap into a wealth of materials knowledge, integrate data from multiple sources, and leverage machine learning methods effectively. By facilitating the development of advanced materials with targeted properties, the OPTIMADE API contributes to solving critical societal challenges and supports the transition towards a more sustainable and technologically advanced future.

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ETSF - 19th Young Researchers Meeting

Location: ZCAM Edificio I+D, C/ Mariano Esquillor s/n Campus Río Ebro, Universidad de Zaragoza E-50018 Zaragoza, Spain
Webpage : https://www.cecam.org/workshop-details/1239
Dates: Jun 12, 2023 - Jun 16, 2023

1 State of the art

The Young Researchers' Meeting (YRM) of the European Theoretical Spectroscopy Facility (ETSF) is an annual event that brings together young researchers working on theoretical and computational approaches for studying the electronic and optical properties of materials. It is specifically aimed at MSc and Ph.D. students, as well as postdoctoral researchers. In other words, researchers who have not obtained yet a permanent position are eligible to attend, exchange, and present their research work. Over the years, the focus of the YRM has expanded beyond theoretical spectroscopy to include various other fields such as transport, magnetism, spintronics, correlated systems, and multiscale modeling, and more recently, in the current edition, we also included a session fully dedicated to quantum computing. The objective of the meeting is to provide a platform for young researchers to present their work, learn about state-of-the-art theoretical methods in their field and provide insights into related fields to help the ETSF community to grow further and expand their scope with ideas from different geographical areas and research orientations.
To this end, this year's edition of the ETSF YRM 2023 [https://www.etsfyrm2023.com], the organizers planned it to take place in the CECAM node in Zaragoza, Spain (ZCAM) in the period of June 12-16th, 2023.
The organizers were committed to provide a friendly and comfortable atmosphere, prioritizing early-stage researchers in the oral sessions, and ensuring equal opportunities for all applicants. Therefore, the feedback the organizers got from the attendees and the invited speakers was invaluable. Everyone enjoyed the event in a friendly and scientific manner.

2 Major outcomes

The conference was divided into five sessions: advanced electronic methods, optical properties, vibrational properties, strongly correlated systems, and quantum computing. The first four sessions covered much of theoretical spectroscopy and were kept to be the same as in past editions. Invited speakers opened the morning and afternoon sessions of each day, introducing the concepts and techniques of each specialty.
The conference started with a description of random phase approximation (RPA), with an overview of the theory, its applications, limitations, and advantages over other techniques. The afternoon session on electronic advanced methods dealt, among other topics, with an extension of the selected configuration interaction (SCI) methods to a transcorrelated approach, which significantly improves their convergence. This description is very nice! Do you think we should also add the names of the invited speakers who gave the talks? Maybe not for the CECAM report but what about for Psi-k?
On the second day, two different techniques for calculating optical properties were presented. The first one using the localization landscape theory and the Wigner-Weyl approximation to reproduce the absorption spectra observed experimentally in mixed halide perovskites. The second invited speaker presented the theory and experience of near-field spectroscopy using tunneling microscopy.
During the morning session devoted to vibrational properties, methods to faithfully represent the paraelectric and ferroelectric phases were discussed, including the whole configuration of

local minima between these two phases. In the afternoon, a different topic was presented: the anharmonicity of phonons in quantum paraelectrics. After the talks on vibrational properties, there was a poster session where participants who did not have a talk could present their work, many of them devoted to the use of machine learning techniques.
The fourth session started with a brief introduction to the metal-insulator transition of the Hubbard model and the different effects, including local and non-local ones. This was followed by a lecture on unconventional superconductivity in bulk and tri-layer alkali-doped fullerides.
The last session of the conference moved away from spectroscopy and, as it is usual for the YRM, it changed with respect to previous years to introduce new and emerging techniques, such as quantum computing. Here we discussed the different techniques that exist today and are being investigated to work with quantum computing. We projected what are their advantages and limitations with respect to classical computers and in which areas they can be most useful.

3 Community needs

Computational Infrastructure:
One of the primary needs of the community of YRM and ETSF is to have access to robust computational infrastructure. This includes both hardware and software resources. Researchers require access to high-performance computing (HPC) resources to tackle complex computational problems effectively. HPC systems provide the necessary computational power and parallel processing capabilities required for simulations, data analysis, and modeling.
In addition to HPC resources, the community also benefits from existing codes and software libraries. The availability of well-documented and optimized codes allows researchers to build upon existing work, accelerating the pace of scientific discoveries. Promoting code sharing and providing platforms for code repositories enables researchers to collaborate, reproduce results, and leverage each other's expertise.
Networking:
Establishing networking channels for YRM and ETSF can be achieved through various means. Joint conferences, workshops, and seminars bring researchers from different backgrounds together to share their work, insights, and challenges. Such events provide a platform for interdisciplinary discussions and foster collaborations between computational scientists and experimentalists. Online platforms, forums, and social media groups also play a significant role in connecting researchers, allowing them to exchange ideas, seek advice, and collaborate remotely.
Event Organization:
Organizing events is crucial to meet the needs of the community effectively. In this context, considering a series of CECAM workshops on computational infrastructure and methodologies is highly beneficial. CECAM workshops focus on specific topics and provide an in-depth exploration of the subject matter.
CECAM workshops bring together experts and researchers from diverse backgrounds, creating an environment for fruitful discussions and interdisciplinary interactions. These workshops offer researchers the opportunity to present their work, learn from experts, and stay up to date with the latest advancements in computational sciences. The workshops can cover various topics such as advanced simulation techniques, code development, optimization, and emerging computing technologies.

4 Funding

Typical funding channels for research projects of solid-state physics and quantum chemistry within the European Union include Horizon 2020, Psi-k, and CECAM. In the upcoming calls, potential new sources could emerge, offering additional funding opportunities such as NanoX, CFM Fondation pour la Recherche, which may be worth considering as potential collaborators or funders for joint research proposals.

The organizing members of the YRM change every year, so it is necessary to pass on the information regarding the sponsors from the current year to the next team of organizers. Sponsors from European Union organizations, such as Psi-k and CECAM are among the primary topics of discussion when a new committee is formed. Additionally, the possibility of applying to regional sponsors is also discussed.

5 Will these developments bring societal benefits?

The ETSF Young Researchers' Meeting (ETSF-YRM) and its research topics bring several societal benefits. These topics advance materials science by studying electronic and optical properties, leading to the development of materials with improved conductivity, energy conversion, and durability. This benefits industries like electronics, renewable energy, and manufacturing.
Theoretical spectroscopy contributes to sustainability by enabling the development of efficient solar cells, energy storage systems, and catalysts for clean chemical processes. ETSF-YRM topics can drive the growth of sustainable technologies, reducing reliance on fossil fuels and mitigating environmental impact.
Understanding electronic and optical properties aid drug discovery and design. Theoretical spectroscopy helps predict molecular interactions, designing drugs with improved bioavailability, reduced side effects, and target specificity. This fosters the development of novel treatments, enhancing healthcare and benefiting society.
Funding opportunities for these benefits exist through government research grants, programs in materials science, sustainable technologies, and healthcare innovation. Collaboration with industry partners can also provide funding for real-world applications.

6 Participant list

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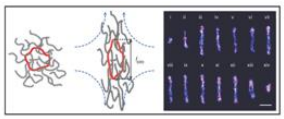

Ring Polymer Dynamics

Location: Monash University Prato Centre in Italy (http://monash.it)
Webpage : https://www.cecam.org/workshop-details/33
Dates: Jun 14, 2023 - Jun 16, 2023

1 State of the art

This CECAM workshop focused on exploring the current state-of-the-art and open scientific challenges for ring polymers, which are macromolecules with a unique architecture that has fascinated scientists for decades. Circular polymers (commonly known as ring polymers) lack chain ends, which results in qualitatively different structure and dynamics compared to linear polymer chains. Understanding how the molecular architecture of polymers affects the complex viscoelastic properties of polymer liquids is a major challenge in materials science and biophysics. At the molecular scale, linear polymer chains slide past each other in concentrated solutions and melts by reptation, but their backbones cannot cross. The dynamic motion of polymers is hence subject to topological constraints, an effect which is familiar from the macroscopic manipulation of knotted strings. However, molecular architecture plays a key role in governing the microscopic topology of polymers. The topological constraints of linear polymers are *transient* and tend to dominate the viscoelastic behavior of high molecular weight polymeric liquids by slowing down chain equilibration after a deformation. In contrast, the microscopic topological state of ring polymer systems is *quenched* during the sample preparation. All subsequent conformational changes preserve the topology and, in particular, invariants characterizing: (i) the internal degree of knotting of individual molecules, (ii) the degree of linking of pairs, triplets, and higher order linkages of rings, and (iii) in the case of double-helical DNA, the number of times the two strands wind around each other. These interactions lead to fascinating emergent effects in ring polymer systems.
The CECEM meeting focused on understanding how the large-scale structure and dynamics of ring polymers can radically differ from their linear chain counterparts, even given identical chemical composition, molecular weight, and density. In the well-known case of linear polymer chains, molecules mutually interpenetrate and exhibit nearly ideal Gaussian chain statistics. In contrast, in a melt of unknotted non-concatenated rings, individual ring polymer molecules exhibit territorial behavior with high molecular weight rings further displaying self-similar territorial packing in their crumpled internal structure. The stark differences in molecular structure between linear and ring polymers hold important implications for understanding their dynamics in the melt state.
The study of ring polymers has a rich history spanning experiments, computational modeling, and theory. Experimental studies in the 1970s and 1980s focused on preparing and characterizing synthetic non-concatenated rings in dilute solutions and melts. Early work focused on different ring polymer chemistries, and rings were typically purified and characterized using size-exclusion chromatography, light scattering, and shear rheology. Overall, this early work began to reveal the influence of linear chain impurities on the rheological properties of ring polymer melts and motivated methods to improve ring purity. In the early 2000s, the development of liquid chromatography at the critical condition (LCCC) was shown to provide enhanced purification of ring polymers, which set the stage for subsequent rheological characterization and current state-of-the-art rheological and structural experiments on ring polymer melts.
Modern theories of polymer dynamics and rheology were originally developed for individual molecules topologically confined and diffusing through an array of fixed obstacles. In terms of molecular theories, the current state-of-the-art includes: (1) the double-folded lattice animal model, (2) the fractal loopy globule model, and (3) a force-based theory for ring polymer liquids. In terms of experiments, the rheological properties of ring polymer melts and concentrated solutions is a frontier problem in polymer physics. The development of liquid

chromatography at critical condition (LCCC) provided a method for enhanced purification of synthetic rings, setting the state-of-the-art for preparing and characterizing ring polymer melts. In terms of biological systems, interest in ring polymers has been motivated by naturally occurring circular DNA plasmids and genomes.
Overall, the CECAM meeting provided an ideal opportunity to bring together world-leading experts in the field discuss the current state and open challenges in the area of ring polymers.

2 Major outcomes

A major outcome of the meeting was the preparation and submission of a perspective article summarizing the current state-of-the-art and open challenges and opportunities in the field of ring polymers. This article will be submitted to the Journal of Rheology by December 2023. The co-authors of the perspective article include several meeting attendees and leaders in the field, including: Ralf Everaers, Kurt Kremer, Margarita Kruteva, Gregory McKenna, J. Ravi Prakash, Dieter Richter, Rae Robertson-Anderson, Michael Rubinstein, Kenneth Schweizer, Charles Schroeder, and Dimitris Vlassopoulos. In the perspective article, we discuss the current state of the field of ring polymer dynamics, focusing on recent progress in experiments, theory, and computational modeling. We further discuss emerging challenges and opportunities in the field, highlighting open scientific questions that can only be solved by a united community approach and meaningful collaborations to address these important interdisciplinary challenges. This article was prepared based on extensive discussions from the CECAM-funded Ring Polymer Workshop, which was held in June 2023. The article is organized by discussing challenges facing the study of ring polymer using computational modeling and theory, experimental preparation and characterization of synthetic rings, and the study of biological and active ring polymers.
In the context of theory and simulation for ring polymers, open challenges were identified in the following areas: (1) achieving universality in understanding whether the length scale controlling the static properties of rings scales proportionally with the length scale controlling the dynamics of the linear chain analogs; (2) understanding dynamics of knotted or concatenated rings; (3) modeling effective interactions between dense ring solutions; (4) understanding open loops and threading; (5) modeling ring-linear blends that include ring and linear chain topologies, (6) understanding the dynamics of active ring molecules, (7) understanding the origins of slow relaxation dynamics in ring melts and concentrated solutions; (8) modeling ring-ring interlocking interactions in flowing non-dilute solutions.
In the context of experiments on ring polymers, open challenges were identified in the following areas: (1) achieving high levels of ring purity in polymer samples; (2) characterizing slow relaxation modes in ring melts; (3) characterizing the linear and non-linear flow properties of ring-linear blends; (4) understanding the non-linear rheology of ring polymer samples; (5) developing new single molecule methods to study the dynamics of ring polymers; (6) understanding phenomena associated with topological glass transitions in ring melts; (7) extending experiments to materials beyond ring such as soft interacting colloidal particles.
In the context of biological systems involving ring polymers, open challenges were identified in the following areas: (1) developing new theories for bio-based ring polymer systems, (2) developing and carrying out new experiments that effectively bridge length scales between the molecular scale and macroscopic scale in biological ring polymers, (3) understanding the relative contributions of thermal motion and active dynamics in ring polymers undergoing active topological motion such as enzymatic behavior, (4) understanding rheological behavior in time-varying viscoelastic systems.
In all of the areas above, the interactions and presentations at the workshop stimulated lively discussion and motivated ongoing and future research efforts on these frontier problems in polymer physics.

3 Community needs

The community of researchers focusing on fundamental aspects of ring polymer statics and dynamics is fairly small, and we believe the workshop represented a significant fraction. The topic of infrastructural support in terms of HPC facilities, laboratory equipment, PhD student and postdoc positions, and the like, was not discussed at the workshop, and our impression is that the present level seems more or less sufficient. However, networking and exchange within the existing community was and is considered as highly useful and beneficial, and it seems that our workshop has filled an important gap. We do expect that repetitions of this meeting in the future will be responded to in a similarly positive fashion. However, given the relatively small size of the community focused on ring polymer physics, progress in the field is steady but not extremely rapid. Therefore, we believe that a repetition on (for example), an annual basis would probably be too frequent, while a tri-annual repetition may perhaps be appropriate. It is probably the best to not cast this into a rigid calendar scheme, but rather to react flexibly to new developments.

4 Funding

Several potential future funding channels were identified at the workshop. In addition, several meeting attendees discussed the development of joint proposals. For US-based researchers, the Department of Energy (DOE) provides several opportunities for fundamental research in the area of sustainable or recyclable polymers. New ideas could include understanding and leveraging the role of molecular topology on developing new sustainable materials based on ring polymers. In addition, the National Science Foundation (NSF) provides opportunities for US-based researchers for basic research in the area of ring polymers. Similar statements hold for most nations represented at the workshop (e.g., DFG for Germany, ARC for Australia, etc.).

5 Will these developments bring societal benefits?

Several examples of ring polymers or phenomena involving "loopy" polymers are often found in nature. A common real-world example of long "untangled" chain molecules can be found in the cell nuclei of eukaryotic organisms, where the chromosomes occupy territories resembling those found in ring polymer melts. Although the crumpled internal structure of chromosomes was theoretically predicted based on molecular topology, the extent to which this analogy extends to linear chromatin fibers depends on a separation of time scales. Understanding the behavior of looped polymers or DNA-based ring polymers holds the potential to reveal a wealth of information regarding the dynamics and behavior of biological systems, and further, this information could hold the key to developing new human-based therapies. For example, computer-based simulations of decondensing chromosomes have revealed territories that are stable over biologically relevant time scales and chain structures, in good agreement with experimental data for chromosomes and the local crumpled equilibrium statistics for corresponding melts of non-concatenated rings. Integration of new experiments and simulation/modeling provides a powerful approach forward for understanding biological polymers with non-linear topologies. Moving beyond linear or circular genomic DNA, ring polymer physics critically underlies the dynamics of supercoiled rings, topological composites involving rings and shorter linear chains (e.g., peptides), topologically-active DNA rings such as nucleic acids undergoing enzymatic editing, kinetoplasts, and more complex chromatin loops. Overall, this workshop considered the key challenges that need to be addressed to advance our understanding of biological and bio-inspired ring polymer systems that play a critical role in fundamental life processes.

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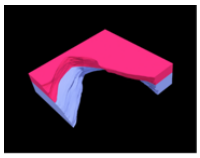

3D cracks and crack stability

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1196
Dates: Jun 14, 2023 - Jun 16, 2023

1 State of the art

The fracture of solids has formed the cornerstone of engineering science since Galileo first posed the question of the maximum load before rupture of a beam subjected to tension. Our current understanding of the mechanics of fracture is formulated in the theory of linear elastic fracture mechanics, which predicts a singular stress at the crack tip, making the problem challenging on all levels. Experiments show that the mechanics and physics of brittle fracture are typically irregular, with the emergence of surface features and texture that are non-smooth. Even when a crack abides the over-all symmetry of planar loading conditions, characteristic fracture surface structures emerge with a strong velocity dependence, and can even persist at extremely low velocities. The emergent structures are indicative of non-linearities in the dynamics of a crack, and are the hallmarks of crack instability.
The long-standing paradigm in fracture mechanics, established from linear perturbation theory, is that any initial disturbance should decay or disperse, independent of its amplitude. Recent calculations challenge this paradigm [1-3], and instead suggest that due to non-linearities in the dynamics, the crack surface is susceptible to breaking planar symmetry for sufficiently large disturbances. Experiments support these calculations, as even quasi-static cracks exhibit structure and surface features that do not decay as the crack progresses [4]. Indeed, such disturbances can have global consequences, as a rigid inclusion can completely arrest a propagating crack [5].
Recent numerical calculations using the phase-field method are capable of reproducing the texture and features of these dynamics, if at an altered threshold velocity for the onset of instability [6]. A similar numerical method shows that a quasi-static crack subjected to mixed mode-I / mode-III loading will readily develop lances and a corrugated pattern [7]. In both cases, the overall planar symmetry of the crack is broken, and a fully-3D stress state develops at the crack tip. This is significant, because such a stress state is extremely challenging to address analytically, and nearly impossible to characterize using existing experimental methods. While these numerical calculations led to advances in the methods available to the numeri cist to calculate the mechanics of more complex crack tip loading conditions, fundamental questions about the precise value of the threshold for the development of e.g., lances, or microbranches in the dynamic case, remain unanswered.
Experimental developments using a variety of materials are now positioned to inform numerical calculation on the most general loading cases, including fully 3D loading conditions, and mixed planar/ non-planar loading. Indeed, direct observations of crack tips in brittle hydrogels emphasize the sensitivity of a crack to mixed-mode loading conditions [8], and even the emergence of planar symmetry breaking [9]. Method development, including direct microscopic measurement of crack tip opening displacement and deformation [10], or more sophisticated speckle-holography methods [11], stand to facilitate direct measurement of 3D deformation field, specifically for materials under high-strain near sharp geometries such as a crack tip.
Taken together, these advances suggest that the field will benefit from an opportunity to identify key outstanding questions and discuss the best approaches to improve predictability of material failure in the most general 3D case.

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*[11] S. Aime, M. Sabato, L. Xiao, D. Weitz, Phys. Rev. Lett., **127**, 088003 (2021)*

2 Major outcomes

This workshop on the 3D cracks and crack stability provided a platform for researchers to present their latest findings and discuss key themes in the field. The workshop was organized into six half-day sessions that spanned three days, covering three overarching themes. The first theme focused on the state of the art of analytical approaches and numerical modeling of crack front instabilities under mixed-mode loading conditions. The second theme focused on frictional rupture dynamics and nucleation of frictional rupture. The third theme centered on the interaction of cracks with elastic heterogeneity and planar symmetry breaking.
In these discussions, a number of outstanding questions in each theme were identified that would constitute key developments in the field. Only select speakers are referred to here, while all participants and speakers contributed significantly to the framing of these questions.

3D calculation methods and numerical approaches with phase-field modeling of crack front instabilities:

1. *Can LEFM be extended to arbitrary crack front geometries by perturbing the crack tip geometry and calculating the resulting stress intensity factors?*
   Leblond presented an extended Bueckner-Rice theory for arbitrary geometric perturbations of cracks, work carried out in collaboration with Lebihain. This work highlighted how analysis based on LEFM can be extended to arbitrary crack front geometries perturbatively. This framework offers an analytical alternative to Movchan-Gao and Willis's work. The theory can be used to determine stress intensity factors at higher order for non-planar cracks. This work is likely to see application to crack front instabilities subject to far-field mixed mode-I – mode-III loading conditions, highlighted by Lazarus's work.
2. *How important is Gamma convergence for phase field calculations of crack dynamics?*
   Contributions from Karma and Molinari both highlighted the ability of phase-field modeling in a finite-element framework to capture key 3D behaviors of propagating cracks. Because this is a readily accessible and widely-used method, it is important to establish where it might be limited in generating physically relevant output. Whereas Karma's work centered on lance propagation in 3D, Molinari's work focused on dynamic crack advance and instability of dynamic crack fronts. These two works highlight the merits of phase field in the insights it has provided phenomenologically, and raise intriguing questions about how quantitatively it can capture fracture behaviors.

Friction and earthquakes:

1. *How much does the 3D nature of a frictional interface or fault impact the dynamics of frictional rupture?*
   A number of contributions focused on the dynamics of fluid-driven rupture in the context of earth sciences. This work is not only critical in establishing a post-mortem understanding of seismic events, but in understanding and possibly predicting future seismic events. Jean-Paul Ampuero highlighted how 3D modeling is used in this context, as it can accurately represent fully 3D fault structures that by their 3D nature

generate dynamics that are not represented by a reduced geometric model, and identified shortcomings in the current approach, which cannot readily extend models of planar rupture to 3D multi-fault networks, where fault interactions dominate. Elbanna used 2D fault models to explore the role of off-fault plasticity in modifying the fault system dynamics, identifying novel emergent behaviors that emerge from plasticity. The importance of fluid injection was explored by several participants including Lecampion, who demonstrated an experimental system that can track off-crack damage using acoustic emissions, and can capture the growth of a radial crack from a fluid injection site.

2. *Under what conditions will a frictional rupture nucleate?*
   The highlight here was the work of Fineberg and Adda-Bedia, which contended that frictional rupture nucleation in a finite geometry is always sensitive to system size. This generated a vibrant discussion, as several participants expected scale separation at the earliest moments of rupture, raising the key question of which conditions govern frictional rupture nucleation.

Interaction of cracks with elastic heterogeneity and planar symmetry breaking:

1. *How much does planar symmetry breaking affect the ostensible toughness of a material?*
   Planar symmetry breaking featured prominently in several talks – from Lazarus to Karma to Kolinski – in numerics, and in experiments. The focus on mixed-mode-I – mode-III far-field loading symmetry highlighted the 3D nature of planar symmetry breaking. Localized features that appear on the crack front were identified as augmenting the toughness of the material. Suggested mechanisms include enhanced fracture energy in mode-III loading as identified in prior work of Ravi-Chandar, and increased fracture surface area in the spirit of Griffith.
2. *What sets the size of a river-line feature on a crack surface?*
   Given the frequent appearance of river-line / lance features on crack surfaces as one of the primary modes by which a crack breaks planar symmetry, and the measurements of Baumberger and Ronsin (as well as several others including Fineberg), the question of what sets the size of these features was identified by Karma as being a central question in the context of 3D cracks. The question is well-posed, as both Rubinstein's and Fineberg's experiments independently identify a characteristic scale that these features in the crack surface adopt. Baumberger and Ronsin's experiments identify a larger scale than those of Rubinstein or Fineberg, suggesting that there may be a material dependence to this scale. Hypothesized mechanisms include elastic non-linearity or the fracto-cohesive length.
3. *Under what circumstances will the interaction of a crack front with a rigid elastic inclusion drive a crack to break its planar symmetry?*
   Rubinstein and Henry both spoke about cracks interacting with elastic inclusions – Rubinstein from the perspective of ensembles of particles, studied with experiments, and Henry from the perspective of a crack interacting with a single inclusion, with numerical simulations and periodic boundary conditions. Both talks stressed the role of inclusions in triggering secondary crack front structure formation, such as lances or river lines. Weitz's studies of hydrocracks identified localized pinning sites for a radial crack, which might emerge due to material heterogeneity, and lead to anomalous crack progress.

While the above summary identifies central questions along three primary workshop themes, other speakers identified great questions, from fundamental crack propagation in swelling hydrogels (Driscoll) to the fracture energy of lithium (Pharr). In all cases, a need for experimental data, validation of numerical approaches, and theoretical advancement were identified.

3 Community needs

In identifying the key questions under the three themes listed in the Major Outcomes for the workshop, several community needs were highlighted. These centered around experimental data on 3D cracks, validation and verification of numerical techniques, and validation of recent theoretical developments that extend existing theory beyond linear perturbations. Indeed, the work of Kolvin, presented in a poster, and Leblond highlighted a path forward for theoretically calculating stresses around 3D cracks. Experimental measurements of 3D stresses and deformations will provide a sound vehicle for the evaluation of these theoretical approaches. The same experimental data could be used to validate e.g., phase-field calculations of 3D cracks.

Weitz, in recent work, stressed the possibility of obtaining fully 3D data using light scattering. This method will undoubtedly prove useful in the endeavor to obtain fully 3D deformation field data near a crack tip. Other methods, including those of Kolinski and co-workers, focus on tracking particles – while more intensive in terms of sample preparation, the directness of such methods can prove useful as a means of obtaining deformation data.

The friction community has a clear need for predictive capability, particularly in the context of earth sciences and geo-energy recovery. Predictive models that capture the multiscale nature of complex frictional sliding and nucleation are called for, and could have concrete impacts for society, as discussed below. Integrating data-driven approaches with traditional modelling techniques and machine learning could lead to more accurate predictions of frictional nucleation and sliding.

As a final note, through the talks of Pharr, Subhash and Van Innis, the workshop identified the importance of addressing real-world applications and engineering challenges related to 3D fracture. Understanding the mechanical behavior, failure mechanisms, and reliability of amorphous solids under different loading conditions is crucial for their practical utilization in manufacturing and healthcare industries. Bridging the gap between fundamental research and practical applications would require close collaboration between academia, industry, and policymakers.

4 Funding

Our community typically relies on funding from various state-sponsored institutions including NSF, SNSF, ERC, among others. DOE and DOD have traditionally supported fracture research, as well.

Industrial partnerships can increasingly play a role in applied fracture research, as demonstrated by the potential collaborations including e.g., the adhesives industry (Van Innis).

5 Will these developments bring societal benefits?

Fracture mechanics is central to all of engineering science, as it forms the foundation for structural integrity. As such, the broad field of fracture stands to concretely improve the prediction and prevention of structural failure. The focus of this workshop on 3D cracks is a sub-field in this critical domain of research. Insofar as fully 3D cracks stand to toughen brittle materials, this sub-field can significantly enhance robustness of structures formed using traditional construction materials.

The field of friction stands to directly benefit seismically active regions, as well, in potentially arriving at additional time to evacuate before seismic events.

Some concrete examples of how 3D fracture can lead to societal benefits follow:

Engineering science: The improved understanding of the mechanical response and structural properties of complex fracture fronts can stimulate the development of novel approaches to enhance structural integrity. Applications for these materials are ubiquitous, spanning domains from construction to aerospace and automotive applications. Pressure vessels in the context

of energy generation, airplane fuselages and ships all stand to benefit from an enhanced toughness arising from a fundamental understanding of 3D fracture.
Earth science: A core theme of the workshop focused on nucleation of frictional rupture and frictional dynamics. Faults are generally complex, and elastic interactions over a fault zone that stem from their fully 3D structure can fundamentally alter the nucleation and slip propagation events that emerge during an earthquake. A fundamental understanding of 3D fault zone dynamics may lead to enhanced predictability, thus avoiding loss of lives and property.
Environmental Impact: Enhanced structural integrity directly leads to prolonging useful structural lifetime. This generates less waste, leading to more efficient use of resources.

6 Participant list

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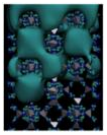

Fluids in porous materials: from fundamental physics to engineering applications

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1203
Dates: Jun 19, 2023 - Jun 21, 2023

1 State of the art

Fluids confined in porous materials have relevance in many fields ranging from chemistry and physics to biology and engineering. Key questions considered during the last ten years are summarized in the first column of Fig. 1. These questions include thermodynamics and statistical mechanics of confined systems, reactivity under confinement, transport properties of confined fluids, mechanical properties of porous solids used to confine fluids. Refraining from giving an exhaustive description of all these questions, it is interesting to notice how thermodynamics of confined liquids allowed one of the speakers to investigate the temperature of planet Earth in remote eras (paleotemperature determination). A significant number of participants are focusing on the exploitation of fluids for harvesting energy. Here, the efficiency of mechanical-to-electrical energy conversion, i.e., the fraction of energy used to push the liquid through the nanopores which can be converted into electric current, is still disappointingly low. Other strategies for energy conversion (thermal-to-electrical and mechanical+thermal-to-electrical) include evaporation of liquids wetting porous electrodes and solid/liquid triboelectric nanogenerators. Also, in these cases achieving satisfactory conversion efficiencies is the challenge to be addressed.

2 Major outcomes

In this section, we report the major outcomes of the workshop grouping them by topic. We start from energy production based on the difference of salt concentration between two solutions, so-called “osmotic energy” or “blue energy”. This idea is not new but its application has been highly inefficient for many decades. An article published in 2013 [Siria et al., Nature 2013] revived the field showing a very large, osmotically induced electrical current generation for a prototypical system made of a single boron nitride nanotube piercing an ultrathin membrane and connecting two fluid reservoirs at different solute concentrations. Despite this progress, many challenges need to be overcome to achieve relevant efficiency. In membrane-based technologies the main challenge to the exploitation of blue energy is represented by the so-called concentration polarization, i.e., the accumulation of ions in the vicinity of one of the membrane surfaces which severely decreases the available concentration gradient across the membrane. One of the ideas presented during the workshop is related to the use of the intrusion-extrusion process in nanopores to deal with this issue. In one implementation, instead of continuous flux membranes, nanoporous materials were flushed alternatively with saline solutions and fresh water, while pressure cycles allowed to use the nanopores as molecular sieves for the ions; this approach avoided the accumulation of charges typical of continuous flux membranes. In a different implementation, the use of nanofluidic channels connected through angstrom scale pores allowed for the drastic reduction of the concentration gradient, thus limiting the typical drawbacks of membrane technologies. Significant insights into origin and mechanism of concentration polarization were presented that may help bring the blue energy concept closer to application. Contact electrification upon intrusion-extrusion process was also reported. It was shown that one can increase the surface area available for solid-liquid electrification by using nanoporous materials instead of nanorough surfaces. However, challenges related to making an electrical connection to collect charges from nanopore surfaces, e.g., by realizing conductive monolithic nanoporous materials, are evident and can be a limiting factor in the development of intrusion-extrusion electrogenerators.

A topic common to many application domains is the mechanism of intrusion of fluids in porous materials. Understanding this mechanism allows one to devise principles to design porous materials with targeted intrusion/extrusion characteristics. Experimental and theoretical techniques have been used to investigate this process. Two main mechanisms have been considered: i) capillary condensation, mainly relevant for hydrophilic pores, where cavities of the porous system get filled by water vapor and when a critical value is reacted it condensates, ii) liquid front advancement, in which the system is characterized by a two-phase vapor/liquid system, with the confined front between the two which advances or recedes depending on the thermodynamic conditions. Distinguishing between the two mechanisms is especially difficult due to the fact that both would result in similar general macroscopic characteristics, namely, a hysteresis cycle in the P-V plane. Nevertheless, simulations have shown that in conditions of quasi-equilibrium front advancement is the most likely process. It was also found that very narrow apertures (typically of the size of a water molecule) connecting main cavities of the porous material are critical to control the intrusion/extrusion characteristics of these systems. In the future, it will be very important to investigate non-equilibrium effects, whether the timescale over which intrusion takes place alters the mechanism.
In several of the fields mentioned above, porous materials are used under high compressive or tensile stress conditions. Sometimes the stress is hydrostatic or isotropic, other times is unidirectional. It was shown that some porous materials, e.g., MOFs, have complex stress/strain characteristics. For example, cubic systems such as ZIF-8 still present a complex 3D stress/strain map. For less symmetric MOFs the stress/strain relation is even more complex, with elastic-to-plastic transition strongly depending on the crystallographic direction along which stress is applied. Both elastic and plastic transformations in MOFs are accompanied by changes in the molecular structures of these systems which, given the very narrow size of their cavities, can have an important effect on the characteristics of confined fluids. A Young's modulus vs Hardness chart was presented where the mechanical characteristics of some relevant porous and non-porous materials is reported. It was suggested to share and update this chart within the community to try to rationalize the mechanical characteristics of porous materials and their effect on the properties of confined fluids.
The main conclusion, here, is that the mechanical characteristics of these materials, which are often overlooked in the study of confined fluids, must be carefully considered and tailored to the specific application. For instance, it was shown that MOFs can be loaded with drugs with the aim of selectively triggering the drug release on the target site, flexibility of the porous matrix could provide the required control parameter for a more efficient drug loading and release.

3 Community needs

In order to face common challenges, this meeting was welcomed by all the participants, which belonged to rather different fields. On the one hand, atomistic simulations are emerging as an invaluable bridge between microscopic structural information and macroscopic quantities of experimental interest, while being the tool of choice to simulate crystalline nanoporous materials like MOFs. On the other hand, simulations face multiscale challenges in time and space, which call for specialized rare-event and coarse-grained approaches, in addition to the development of reliable force fields. On the experimental side, the scatter and reproducibility across different laboratories of data is still an issue especially to be able to connect directly with microscopic observables. The need for round-robin tests is emerging to distinguish the genuine variability in the samples, e.g., due to defects in the porous structure, from limitations in the experimental techniques. Such tests, however, would require a stable community platform capable of coordinating such effort. The gain however will be high both for model developers and for applications, enabling the development of quantitative simulation tools and a more stringent control on the properties of devices alike.

4 Funding

We have discussed funding opportunities among participants. The need to form a larger and more cohesive base has been recognized by all. The starting point could be applying for funding to build a network, e.g., via COST actions. In turn, such a networking and collaborative opportunity is expected to spark more collaborative funding opportunities oriented both to fundamental and applied research. A second CECAM meeting on the topic of fluids in porous materials has also been recognized as an invaluable opportunity to form a community and share ideas. Two of the participants, J.C. Tan and P. Asinari, will coordinate the submission of a proposal at the 2024 CECAM call, involving researchers dealing with synthesis of MOFs as well as interested industrial partners.

5 Will these developments bring societal benefits?

Several pivotal technologies could benefit from the developments on the topic of this CECAM meeting on fluids in nanopores: energy applications (blue energy, vibration control and harvesting), drug delivery via MOFs, improvement of separation technologies (stationary phases of HPLC columns), and biomedical developments in the origin and treatment of channelopathies. Simulations are expected to play a major role in translating knowledge into societal benefits as it can provide the missing quantitative tools for the computer aided engineering of new devices.
Interestingly, this workshop has been sponsored by two H2020 European Innovation Council (EIC) Future and Emerging technologies (FET) projects. FETs are high-risk-high-gain projects aiming at developing disruptive technologies, indicating the potential societal impact of the theme discussed in this workshop. Themes with high potential societal impact related to the workshop that have not been discussed include innovative confined nanosemiconductors. This is expected to be a major theme in the close future, especially considering the limitation imposed by China on some semiconductor materials, such as gallium and germanium.

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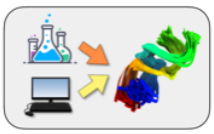

RNA dynamics from experimental and computational approaches

Location: IBPC, 13 Rue Pierre et Marie Curie, 75005 Paris
Webpage : https://www.cecam.org/workshop-details/1215
Dates: Jun 26, 2023 - Jun 28, 2023

1 State of the art

Ribonucleic acid (RNA) molecules play a fundamental role in life sciences. RNAs are the only class of molecules that can both store genetic information and perform catalysis. In the cell, non-coding RNA molecules are pivotal for regulating gene expression at various stages. Regulatory RNAs are hence emerging as promising therapeutic targets for either small molecules or, for complementary, natural or artificial, antisense oligonucleotides. Importantly, RNA molecules are highly dynamic, and thus determining the ensemble of conformations that they populate is crucial not only to elucidate their biological functions, but also for their potential use as therapeutic targets. Computational techniques based on molecular dynamics (MD) simulations enable these structural ensembles to be reconstructed at atomistic resolution. However, the accuracy of the employed energy models is limited, and thus experimental data are required to validate or refine the structural ensembles determined solely by MD. From a complementary perspective, experimental techniques, such as nuclear magnetic resonance (NMR) spectroscopy, cryo-electron microscopy (cryo-EM), and, at a different scale, small/wide-angle X-ray scattering (SAXS/WAXS) and chemical probing experiments, can be used to measure properties of RNA structural ensembles. However, in most cases these techniques report structural information that is averaged over the structural ensemble, often at limited resolution, and therefore can benefit from integration with accurate physico-chemical models via advanced modeling tools.
Over the past decades, a variety of methods that integrate MD simulations and experiments have emerged. Strong interactions between theoretical and experimental groups are fundamental to further advance the development of these approaches, obtain a comprehensive, high-resolution understanding of RNA dynamics, and ultimately create novel

opportunities to develop therapeutic approaches targeting RNAs, also exploiting the conformational dynamics for selective targeting of specific RNA states.
In light of these recent exciting developments, the CECAM workshop "*RNA dynamics from experimental and computational approaches"* was organized in Paris, on June 26-28, 2023 by Massimiliano Bonomi (Institut Pasteur - CNRS), Giovanni Bussi (SISSA), Paraskevi Gkeka (Sanofi), and Michael Sattler (Technical University of Munich - Helmholtz Munich). This workshop gathered scientists from academia and industry with selected contributions from participants to discuss state-of-the-art computational methods, their integration with experimental data, and applications to RNA structure, dynamics, and function.

2 Major outcomes

The CECAM workshop "*RNA dynamics from experimental and computational approaches"* provided a great opportunity to discuss the state-of-the-art and future perspectives of understanding and leveraging RNA dynamics. An animated discussion session evolved around several questions that emerged during the scientific presentations.
How can one properly compare and integrate experimental data and computational simulations? Simulations can produce a vast amount of structural and dynamic data, which in many cases can be directly validated against raw experimental information. Compared to a few decades ago, the amount of raw data deposited on the web has significantly increased, enabling computational groups to directly use this information. At the same time, many modeling tools are becoming more and more accessible to the experimental community, thanks to their comprehensive documentation and increased usability. However, in both computational and experimental areas, significant experience is still required to judge the reliability/quality of the produced information, especially when advanced computational or experimental techniques are used. Direct collaborations between experimental and computational groups are therefore recommended to make the best out of the techniques developed by both communities.
How can the accuracy of current force fields used in molecular dynamics simulations be improved? Whereas current prediction tools can model individual RNA structures from first principles at a reasonable accuracy, MD force fields still have some limitations in accurately describing RNA dynamics, for example, due to a poor treatment of the interaction between divalent cations and RNA and the lack of polarizability effects. As a matter of fact, for flexible RNA oligomers, it is still difficult to model structural ensembles that are in agreement with experiments and avoid overfitting. These limitations make the integration with experimental data even more important. Experiments can be used to refine ensembles and provide fundamental information for improving MD force fields.
How can artificial intelligence approaches be leveraged? Artificial intelligence and in particular deep learning methods have revolutionized the field of protein structure prediction and are increasingly being explored for their potential to reconstruct protein dynamics as well. Applications to RNA have been relatively scarce so far. This might be a consequence of the significantly smaller number of available structures that can be used to train these tools. In addition, the fact that RNA sequences are composed of a more limited and homogeneous alphabet makes extracting useful co-evolutionary information more difficult. Observing the developments of this field over the coming years promises to be intriguing.
How well do we understand and can predict RNA-protein interactions? The difficulties discussed above are amplified in the case of RNA-protein complexes, where the number of interactions that should be properly modeled or probed is combinatorically increased. This is an area of research in which artificial intelligence structure predictors have just started making their contribution, as demonstrated by the recent release of RoseTTAFoldNA and the announcement of the forthcoming version of AlphaFold.
How to assess the biological and pharmaceutical relevance of RNA structure and dynamics? Experimental data suggest that RNA structures are highly dynamic, and therefore an individual structure is in most cases not sufficient to explain measurements performed in solution. However, this observation is *per se* not suggestive of the relevance of RNA dynamics *in vivo*. In this sense, biophysical studies performed *in vitro*, possibly complemented with advanced

modeling techniques, can suggest the coexistence of multiple structures and help generate hypotheses regarding the possible mechanisms of action *in vivo*. These hypotheses could be further validated by performing biological assays including mutations designed to alter RNA dynamics in a controlled manner. Similarly, exploiting RNA dynamics in pharmaceutical applications has unique potential for innovative therapeutic approaches, but still has to be fully demonstrated. It is however very reasonable to expect that standard rigid-docking approaches might fail in characterizing the interaction of flexible RNA with drug-like molecules.
Future perspectives. The CECAM meeting organized in Paris has been very successful in bringing together a heterogeneous community composed of computational and experimental scientists with strong expertise in different techniques to predict and measure RNA dynamics. Established researchers and early-career scientists presented their work in the various sessions, and thanks to the informal setting, early career scientists were able to directly interact with more experienced colleagues in the field. The meeting has attracted a lot of attention from the community, demonstrated by a total of 50 applications. Unfortunately, given the limited capability of the venue, only a fraction of the applicants could be admitted. To mitigate this problem, the meeting was streamed to all applicants, thus significantly increasing its outreach. Several new collaborations started during the meeting, and some of the participants are now planning to organize events in the same spirit in different geographical locations to maximize inclusivity and reach a more heterogeneous community. For example, this meeting brought together for the first time the community working on different aspects of RNA structure and dynamics in the Paris area. After the workshop, this group of people has already met twice to discuss more in detail the research carried out in different labs and to foster new collaborations.

3 Community needs

The meeting highlighted the need for bringing together the experimental and computational communities working on studying multiple aspects of RNA structure and dynamics. Strong interactions between theoretical and experimental groups are indeed fundamental to further advance the development of these approaches, obtain a comprehensive, high-resolution understanding of RNA dynamics, and ultimately create novel opportunities to develop therapeutic approaches targeting RNAs, also exploiting the conformational dynamics for selective targeting of specific RNA states. Given the success of this CECAM meeting, we foresee organizing other events in the future, possibly in a location that allows welcoming a larger number of participants. On a smaller scale, this meeting brought together for the first time the community working on different aspects of RNA structure and dynamics in the Paris area. After the workshop, this group of people has already met twice to discuss more in detail the research carried out in different labs and to foster new collaborations.

4 Funding

During the meeting we did not identify possible new sources of funding for workshop and events. However, this meeting created new connections between participants located in different universities in Europe and USA. We therefore foresee for the future to establish new collaborations and organize events to bring together the experimental and computational communities working on studying multiple aspects of RNA structure and dynamics. CECAM will certainly be one of our go-to resources for organizing such events.

5 Will these developments bring societal benefits?

One particular aspect of this workshop was the discussion of pharmaceutical applications targeting RNA molecules. Yann Foricher (Sanofi, France) provided an overview of recent developments and promising efforts in this area. Since the discovery of messenger RNA in 1961, knowledge about RNA biology and different RNA types as well as their functional role has been increasing exponentially. This paved the way to design strategies to target RNA or to use natural or artificial nucleic acids as therapeutic modalities. Ribosomal antibiotics were the first small molecules to be developed and approved by drug agencies. Outside antibiotic drugs, RNA has been a challenging target for small molecules for many years, due to lack of selectivity. Over the past 15 years, understanding of *in vitro* and *in vivo* RNA biology, progress in structural biology, and several technical developments have paved the way to discover selective and potent drug-like molecules in a rational manner. Biotech and pharmaceutical companies are pursuing various approaches to achieve such a goal focusing on four different areas: RNA translation, RNA splicing modulation, direct RNA targeting, and epitranscriptomics. Recently, following the impressive work carried out by Roche Pharma, PTC and Spinal Muscular Atrophy (SMA) Foundation, risdiplam was approved by FDA for SMA Disease based on its efficacy, selectivity, and safety clinical data. This clearly represents a key milestone for RNA-small molecule drug discovery. Despite some remaining challenges in this new R&D efforts for small molecules, especially in RNA splicing modulation and direct RNA targeting, the first molecules designed by a rational approach were expected to soon enter into clinical trials and indeed Skyhawk Therapeutics recently announced SKY-0515 small molecule candidate targeting Huntington's disease (HD) entering Phase I. In the future we foresee organizing events in which the presence of researchers from pharmaceutical companies will be even more substantial.

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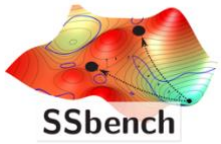

Saddle point Search algorithms: towards the definition of a common BENCHmark framework

Location: CECAM-FR-GSO, LAAS-CNRS, Toulouse, France
Webpage : https://www.cecam.org/workshop-details/1222
Dates: Jun 27, 2023 - Jun 29, 2023

1 State of the art

Given the growing need for accurate and robust simulations in complex systems, there's a call to unite developers and contributors of the saddle search algorithms in materials modeling to create a comprehensive benchmark framework, similar to those successfully implemented in other areas of computational materials science.
The existing initiative OptBench, offers specific well-defined tests to evaluate the performance of saddle point algorithms. These tests primarily gauge performance based on the number of force calls required to complete them and limit tests to empirical interatomic potentials on specific systems.
To overcome this constraint and provide a more encompassing evaluation, the SSbench workshop has been organized.

- SSbench seeks to broaden the scope of benchmarks to encompass a wider range of scenarios, including molecular reactions, surface reactions, and diffusion processes in bulk materials.
- SSbench aims to establish well-defined criteria for assessing algorithm performance. This evaluation considers accuracy but also factors such as speed, robustness, and versatility to ensure a more comprehensive appraisal.
- In addition to expanding the benchmarks and performance criteria, SSbench has the ambition of making benchmark data more accessible. This involves considering strategies to make the data readily available to the materials modeling community.
- SSbench intends to support the development of common workflows and analysis tools to enhance the effectiveness and efficiency of the benchmarking process.

The SSbench workshop will serve as a platform for developers and contributors to share their insights and ideas, facilitating collaboration and knowledge exchange. SSbench represents a collective effort within the developer community to enhance transparency and reproducibility, to reduce code and data fragmentation, and to foster the engagement of the younger generation in the development and contribution to the benchmark framework.

2 Major outcomes

The workshop covered a wide range of topics, including computational challenges, materials science, and various simulation techniques, where the need for benchmarking is confirmed. There are several codes available, and they are not comparable in terms of performance, reproducibility, and other factors.

- Issues related to diffusion process and applications: Flat PES, long timescales, applications involving soft and hard degrees of freedom, challenges in defining initial paths for NEB
- Need: need to develop a high-throughput workflow for sampling chemical space, on-the-fly machine learning for long timescales, using machine learning to accelerate the search

- Simulation techniques: differences in algorithm implementations across different codes, emphasizing the importance of predictive simulations and reproducibility, the difficulty of testing modifications and different implementations, especially in ab-initio methods, adaptive KMC, algorithms for predicting transition state structures
- Codes: dimer, NEB, ART...

During the round table several interesting questions have emerged

Configuration of Saddles: One of the key aspects of saddle search involves determining the configuration of the saddles. Whether a saddle is connected to a minimum or not depends on how the coordinate system is defined. Providing an example to clarify the concept is necessary. Additionally, there was a discussion on the number of force calls required to locate a specific saddle or any of its symmetric replicas.

Compare saddle and descriptor: Exploring the comparison of descriptors involves the assessment of known saddle points to verify if the descriptors exhibit similar behavior or "hash" similarly. This evaluation can be conducted by examining a set of minimum energy states and saddle points. By comparing the performance and consistency of descriptors across these key configurations, it becomes possible to determine their reliability and effectiveness in characterizing saddle points and associated energy landscapes. This approach aims to enhance the understanding and evaluation of descriptors within the context of saddle point optimization.

Complete Saddle Search: The notion of a complete saddle search or exploration was also a topic of discussion. This involves starting from one initial state and assessing whether all possible transitions are accessible. A critical question arose: What if your "precision" finds a saddle at 1.51 eV when all known saddles are below 1.5 eV? It was debated whether the algorithm should continue iterating indefinitely, or if it would be more sensible to provide the distribution of energy levels or configurations to ensure completeness in the search.

Failure during saddle search: The prevalence of failures can be discouraging for people. It's crucial to recognize that this situation can potentially lead to a gaming of the system, where individuals only focus on the methods that have previously yielded successful outcomes. However, it's equally important to acknowledge the possibility that some structures may not respond favorably to any method due to their inherent complexity. This situation highlights the need for a nuanced approach to benchmarking that accounts for different levels of difficulty and complexity in saddle point optimization. This way, the field can address the challenges posed by both highly favorable and inherently difficult cases.

Clear and Extensive Documentation: The extent of documentation we offer to contributors and users is a critical consideration.

Open contributions to the Benchmark: We may explore the flexibility of the framework and how much space we allocate for contributors and users to enhance it. One approach is to segment OptBench into different benchmarks, such as Benchmark 1, Benchmark 2, etc., each tailored to specific criteria. A key principle is that contributors must meet the criteria of existing benchmarks before introducing new ones.

Adding Criteria on Completeness: The idea of introducing criteria related to completeness was raised. This would involve assessing the energy distribution of saddles, potentially providing a more comprehensive evaluation of the saddle search process.

Providing Results: A key decision involves what results to provide. Should we offer the best-optimized parameters or default parameters? The consensus leans towards providing the "better best-optimized parameters" to enhance the benchmark's utility. Additionally, we can consider including a link to a "README" document containing parameter values, offering a more detailed description of the calculation methods, not limited to just input details.

Reproducibility: A crucial aspect of our approach is the assessment of reproducibility, where members of the entire community can attempt to reproduce results. Once successful reproduction is confirmed, the results can be added to the OptBench framework. In this context, transitioning to a platform like Git for collaborative work and result sharing would be highly advantageous. Git provides an efficient and organized way to manage and track changes in the code and datasets, promoting transparency, reproducibility, and the collaborative spirit of the community (Git created under gitlab OptBench: https://gitlab.com/optbench/optbench).

Next-generation: All the groups suffer from the “next developers generation” problem. A major limitation for the development/establishment/maintenance (and even just contribution) of benchmark framework and related software and data is the human ressources. In all the groups the succession is not guaranteed, and, in general, it is risky for the younger to invest time when there is not a clear academic pathway for the recognition/capitalization of the effort.

3 Community needs

The primary motivation and major need behind the workshop stemmed from the necessity to establish a common benchmark framework. Coming easily to a consensus on a "memorandum of understanding" and outlining minimal requirements proved relatively straightforward. These requirements include:

Diverse Benchmark Levels

1. Refinement of saddle points (ab-initio)
2. Exploration of saddle points:
    a. Identifying saddles from a minimum (ab-initio): the objective is to locate one or a small number of them.
    b. Comprehensive exploration or exploration within specific energy barriers: starting from a given initial state, determining the available transitions, and compare with available known transitions (example: focusing on Fe-vacancy and diffusion in ice systems)

Subsequent steps:

i) Kinetic Monte Carlo (KMC) simulation (example for Fe-vacancy coalescence)
ii) Identifying scenarios where the harmonic approximation fails (cases where KMC is ineffective).
iii) Addressing rapid events (get rid of them) and performing "coarse-grained handling."

Additional requirements include:

1. Verification of the accuracy of entries by designated individuals, along with the establishment of a periodic job to update the current optbench webpage by copying the git repository.
2. Establishing a feedback channel for communication between contributors and users.

More complex needs entail:

1. Determining how personal investment in benchmarking, such as uploading to the website and documentation, can be recognized and capitalized upon, especially for younger participants.
2. Assessing differences in algorithm implementations in various codes/packages that use the same algorithms.
3. Developing shared libraries to ensure consistency and avoid slight variations in replicas. (personal investment cf. issue i)
4. Enhancing coordination in software development to prevent undocumented or poorly documented improvements from becoming neglected.
5. Exploring investments in software re-engineering and refactoring, particularly with regard to personal investment. (personal investment cf. issue i)
6. Recognizing that these "non-trivial" needs are common to other communities, such as the Electronic Structure Library initiative.

Continuation of Meetings: SSbench workshop has served as a kind of memorandum of understanding. All groups and participants agreed on the need for joining/share efforts, and on the essential actions to take. But, beyond the post-workshop enthusiasm, a key aspect is how to proceed with these meetings and ensure their continued effectiveness. This involves discussing the path forward, including how to facilitate further collaboration and improvements in the framework. Some additional meetings and workshops/schools would be needed to converge on more concrete path ways to gather and share efforts. We are organizing a school with a focus on "long time scale activated simulations." This hands-on school will delve into a range of topics, including diffusion (TCAD), and cracks, with a special emphasis on theory

followed by practical applications closely aligned with the morning sessions. The program includes dedicated sessions where attendees can expect a balance of theory and problem-solving. These sessions will explore topics such as Transition State Theory, algorithms, and continuous models. The goal is to provide a deep understanding of the underlying principles and the practical skills required for these simulations. A proposal has been submitted in parallel with the PSiK CECAM event, and the younger members of the community have enthusiastically stepped forward to take on active roles as drivers of this initiative.

4 Funding

The workshop has been co-financed by CNRS-LAAS, CECAM node and CNR-IOM.
During the round table participants reached an agreement to actively monitor funding opportunities at both the national and European Union levels, with the aim of exploring bilateral or multilateral collaborative proposals. Ideally, it would be extremely beneficial to be able to present a multilateral proposal, with a topic in line with SSBench, that would involve all participants (and beyond).
However, this presents a complex challenge. Defining a joint “research proposal” bringing together groups (and approaches) with similar problem-solving approaches and focuses on software re-engineering, the development of shared libraries and benchmark framework construction take a large share of the budget and PM, is a complex matter and is not something that can be achieved spontaneously. It requires additional meetings and workshops or schools to align on more concrete pathways for securing funding.
On a bilateral basis, two initiatives have been put into motion:
i) a networking project between LAAS-CNRS and RBI has been prepared and won (Croatia-France Embassy);
ii) There is an ongoing discussion about a networking project between RBI and the University of Iceland.
These bilateral initiatives represent steps towards collaboration and networking, which may serve as building blocks for larger, multilateral proposals in the future.

5 Will these developments bring societal benefits?

The developments discussed in the workshop hold significant potential to yield a wide range of societal benefits. Many dynamical phenomena such as interface growth, aging, catalysis, oxidation and ion implantation, depend on the intricate details of the corresponding potential energy surface, in particular, on the critical points which include minima and saddle points.
Some of the saddle search algorithms (such as NEB) which are commonly implemented into most legacy/community codes are routinely exploited in R&D, such as IBM Zurich or STMicroelectronics, EDF, Sanofi, ... While the identification of saddle points on specific materials alone may not directly lead to the creation of highly efficient multi-junction photovoltaic panels, for example, the ability to comprehend and predict the atomistic mechanisms underlying the multi-junction formation process can offer valuable insights for optimizing manufacturing processes and potentially reducing the need for extensive trial-and-error material testing.
In this context, significant improvements in tools and algorithms have the potential to further help and/or even revolutionize various industries.

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Quantum Battles in Attoscience

Location: CECAM-UK-DARESBURY, University College London
Webpage : https://www.cecam.org/workshop-details/18
Dates: Jun 28, 2023 - Jun 30, 2023

1 State of the art

Attoscience is a burgeoning field of research in which the motion of electrons, atoms and molecules on the attosecond (10^{-18}s) scale is the topic of concern. Primarily, our understanding is informed by the interaction of pulses of light (lasers) with the target systems, the electric field driving the ultrafast motion of electrons and subsequent dynamics at the atomic level. These dynamics are key to our understanding of several phenomena of practical interest: charge migration in large molecules is the driving mechanism for photosynthesis, photovoltaic capture, and the operation of the eye for instance, and the dynamics of molecules in tailored light fields may be used to classify chiral species more accurately and efficiently with clear benefits in pharmacology. The ultimate aim of attoscience is to move beyond *understanding*, and actually begin to *control* electronic motion at the attosecond level, delivering new powers to manipulate chemical, biological or electrical processes with light.
The field has been stimulated by huge technological advances over the last several decades. In particular, the development of tabletop laser sources- capable of delivering ultrashort, long-wavelength laser pulses- and the existence of free-electron laser facilitates- sources of extremely high-energy photons- have opened new avenues of research. The theoretical landscape is a mix of large-scale computational approaches, some of which attempt to solve the general problem (which amounts to solving the time-dependent Schrödinger equation (TDSE)), and some which are lightweight, ad hoc approaches, which are applicable to some subset of phenomena or laser regimes.
The major difficulty in understanding these dynamics is that they are horrendously complex. Every electron in a system interacts with every other electron, as well as with the driving laser field and the parent nuclei. Early approaches to modelling the dynamics thus sought to simplify the picture by neglecting inter-electronic interactions, effectively isolating a single particle driven by the laser field. Such approaches were successful in describing the gross features of experiments but, more recently as experimental techniques have become increasingly sensitive, features attributable only to multielectron interactions have been found, leading to an urgent need for theoretical models including the complex, quantum behavior of the constituent electrons.
There has been a recent trend in the field towards using the techniques of attoscience to probe quantum behavior. The interaction between an ionized electron and its parent ion, for instance, is a prototypical example of quantum entanglement- Einstein's 'spooky action at a distance'- and the wave-particle duality of light and matter is inherent in the design and interpretation of attoscience experiments. There remains some controversy, however, over 'how quantum' some of these behaviors really are: interference and coherence, for instance, have perfectly 'classical' analogies which can describe many of the phenomena in attoscience.
This question: 'How Quantum is Atto(science)?' was one of the core themes for the 2023 conference, along with 'Chirality, Symmetry, and tailored fields' and 'The attoscience of solids'. The goal the Quantum Battles in Attoscience conferences has been to explore these areas of tension in a structured way- pitching opposing views against each other as a means of interrogating the core ideas and developing new ones. This avoids the toxic and defensive atmosphere of more conventional workshops/meetings, where every person trumpets their own approach, and any debate is unstructured and destructive. It also provides an ideal platform for young researchers in the field who can provide fresh perspectives without the need for defending their pet project or approach, as is often the case with established researchers.

2 Major outcomes

2023 Conference

The three days of the 2023 workshop were organized around the themes of 'How Quantum is Atto(science)?', 'Chirality, Symmetry, and tailored fields' and 'The Attoscience of Solids'. The 'battle' on each topic will be published as a review article for Nature Physics Reviews.

Chirality, Symmetry, and tailored fields

The major discussion here was around the feasibility of performing large-scale ab-initio calculations to support ongoing experiments. The trend for using tailored light to probe atoms and molecules requires treating the systems in full dimensionality, and the presence of macroscopic propagation effects requires (effectively) multiscale modelling. There are a handful of methods which can address one or other of these problems, but none can solve the entire problem from first principles. This is an open question for the community.

How Quantum is Atto(science)?

As mentioned in an earlier part of the report there are open questions here surrounding whether the effects probed in attoscience experiment can be thought of as truly quantum, and while there is a broadly held view that they are, there was a spirited discussion in support of the opposing view, that they are classical. This is a new avenue for attoscience, and so the coming years will undoubtedly see many more contributions in this area. There are some limitations in that most theoretical methods use the dipole approximation, wherein the light field is treated as classical. Fully quantum methods will require the quantization of light.

The Attoscience of Solids

This is another area where ideas are comparatively new. There were several presentations of theoretical tools for modelling solid systems, and some discussion about the scale of these calculations. There may be opportunities for large-scale computational projects for scaling these calculations up to larger systems. Discussions in the battles centered on two complementary tools- Attosecond Transient Absorption Spectroscopy and High Harmonic Spectroscopy.

2020 conference

The 2020 online conference focused on three areas of tension: 'analytical vs ab initio methods in attoscience', 'tunneling' and 'quantum interference and imaging using intense laser fields. These three battles were written up as articles for a special issue of the European Physical Journal D.'

Analytical vs ab initio methods in attoscience

Currently, various theoretical approaches are employed for investigating attosecond physics. Two contrasting perspectives have arisen: the 'analytical' approach, which involves studying systems using suitable approximations of physical processes, and the 'ab-initio' approach, which entails breaking down systems into their elemental components and analyzing them using fundamental physics, often employing large-scale computations. By focusing on case studies such as above-threshold ionization, High Harmonic Generation, and Non-sequential Double Ionization, this discussion explored the extent and nature of the analytical and ab inito approaches, their relative strengths and weaknesses, and the complementary roles they have played in scientific discoveries thus far.

Tunnelling

A significant source of tension within the attoscience community revolves around quantum tunnelling, which describes the phenomenon of quantum particles traversing energy barriers directly. A longstanding debate exists regarding whether tunnelling happens instantaneously or if it requires a certain amount of time, and if so, how much time is involved.

The discussion focused on the physical observables of tunnelling experiments, theoretical approaches for determining tunnelling time, and the nature of tunnelling itself. This sheds light on why numerous approaches yield differing conclusions, considering the absence of a universally agreed-upon definition of tunnelling.

Quantum Interference and Imaging

When dealing with attosecond timescales, researchers can utilize intense laser fields to harness the interference between matter waves of electrons. This enables the creation of sub-atomic resolution images while retaining the capability to capture dynamic processes occurring within ultra-short timeframes. The discussion examined the distinct physical roles

played by matter waves in two contexts: high-harmonic generation (HHG), which enhances imaging capabilities, and above-threshold ionization (ATI), which generates packets of electron matter waves. By scrutinizing these differences, the study provides a deeper understanding of their respective contributions.

Long term impact

Arguably the largest impact of the Quantum Battles in Attoscience conferences has not been scientific in nature- it has been the disruptive community practices that it has initiated and sustained. Although the original plans for the 2020 workshop were for an in-person event with around 100 attendees, the pandemic-enforced online edition proved to be more impactful than we could have realized. Reaching more than 300 attendees from more than 34 countries the online conference had a significantly larger reach than could have been achieved in-person, especially considering that many attendees would not have had the resources or flexibility to travel to the UK. In the spirit of making science open to all, edited video recordings of sessions from the 2020 conference were made available on YouTube, amassing thousands of views in the subsequent months. We adopted a hybrid scheme for the 2023 edition, and already the videos on YouTube have attracted several hundred views in the few weeks since the event.

The largest ongoing impact however has been the AttoFridays seminar series initiated by the UCL organizers. This series has continued where Quantum Battles left off- sustaining not only a regular 'live' virtual audience at the bi-weekly seminars but also a devoted following of viewers who view the recordings after the event. Some of the biggest names in the field have contributed talks, and the recent addition of 'hot topics' seminars have provided an opportunity for early career researchers to present their work to a global audience. The videos on YouTube have been viewed more than 15,000 times.

3 Community needs

Networking

Quantum Battles has been unique in the field for its approach to controversial topics. There is certainly a need for continued support in this area, we would like to see more workshop series around controversial topics in other fields. We believe three major benefits are

1) **Education**. The format allows us to platform early career researchers, and to give comprehensive, tutorial-style overviews of broader topics (i.e., those which encompass several competing viewpoints). This provides a perfect opportunity for training new researchers, not only in scientific terms, but also giving them the skills of debate, making that a constructive part of the culture, and of working together with people with different perspectives. The informal character of the workshop, which brings together world leaders and early career researchers in a very informal setting, is hugely beneficial, allowing ECRS to learn interactively with, rather than passively from, senior figures in the field.

2) **Controversy**. Ordinarily, at scientific conferences, either one viewpoint will be heavily represented, or opposing viewpoints will be presented as apparently separate, non-interacting ideas. The whole point of the Quantum Battles workshop was to pitch these ideas against each other- not to stoke rivalry or create animosity, but rather to provide a controlled environment for the emergence of new ideas. No one buys the idea that there really is one superior viewpoint or theoretical approach- we know that different techniques or perspectives are more or less valid in different circumstances. But by allowing conflicting ideas to meet, we view them from a new vantage, and new ideas can emerge from the debate.

3) **Inclusivity.** When Covid 19 forced the 2020 Quantum Battles workshop online, we were not expecting that the silver lining would be a hugely increased reach and impact for our meeting. More than 300 attendees from 34 different countries tuned in live to hear talks and participate in discussions, not to mention the thousands of views which have amassed since on the YouTube videos of the recorded sessions. It exposed a huge blind spot in our organization of scientific meetings, which is that online those who live in certain places in the world, or those without access to significant amounts of money, and the flexibility to travel, can attend. It is clear that without targeted intervention, this disparity will continue. In line with points 1. and 2. above, this is harmful to good science. Better ideas will emerge when we include more viewpoints. Although it added a significant amount of expense and effort, we

insisted on streaming all parts of our 2023 'in person' conference online, and are in the process of making edited videos of all talks, panels and battles available on YouTube. This should be part and parcel of all future scientific meetings, but this needs to be factored into both the budget and organization. There is a significant cost in terms of both money and time, but in order to ensure that attendees can still concentrate and participate in the meeting, the burden for streaming and recording should not be borne by the scientists facilitating the meetings, but by the host institutions and/or funders.

4 Funding

There was no formal discussion of funding during the meeting.
Large-scale networks such as AttoChem (EU Cost action https://attochem.qui.uam.es) fund research in this area, but typically most researchers are funded on smaller grants supporting a handful of institutions for more focused projects.
As well as the funding from CECAM, the workshop itself was funded with money from AttoChem, UK Research and Innovation via grants EP/T019530/1 and EP/V05208X/1, The European Physical Journal through the Young Researcher attendance grant and the Institute of Physics.

5 Will these developments bring societal benefits?

The Quantum Battles in Attoscience in its 2020 and 2023 editions (as well as the Ato Fridays seminar series, which was a spin-off of the Quantum Battles) have already been hugely beneficial to the attoscience community and beyond. Apart from being centered around controversial cutting-edge topics, this workshop series has a strong educational component. The preparation takes around three months, in which the panellists (dubbed `combatants') work together towards a joint presentation. Mock battles are necessary in order to give the participants reassurance and, since this is quite a high-profile event, help them overcome their impostor syndrome. The educational component relies on selecting and emphasizing the main points, bringing and holding one's view against opposite arguments, and having a discussion in a collegial and controlled manner. This helps to educate the next generation about debating and collaborating, thus changing the prevalent antagonistic and respectless research culture.
The 2020 edition of the Quantum Battles attracted over 300 participants, being considered the 2020 highlight in attoscience, and the Atto Fridays was the world's biggest attoscience seminar series during the COVID-19 pandemic, with over 100 weekly participants), these events broke new ground in science communication. We have used social media pioneeringly to engage with the public, creating a Twitter profile (@quantumbattles; 237 followers) and a YouTube channel (https://www.youtube.com/c/QuantumBattles) specifically for that purpose. We have broadcasted the conference on our YouTube channel and used Twitter for poster presentations and overall news. We also used Twitter to release physics opinion polls to the public, and even memes and pictures of pets to foster a sense of community. Examples of non-standard participants were the Black Physicists (@BlackPhysicists), with over 27000 followers.
The YouTube channel is also used for the Atto Fridays seminar series and has over 500 subscribers. We have released around 100 videos up to the present date, and they routinely reach hundreds of views (the most popular videos have around 700 views). Both the Quantum Battles 2020 workshop and the Atto Fridays seminar series routinely host leaders in the field, including 2018 Nobel Prize winner Professor Donna Strickland, and Professor Philip Bucksbaum, president of the American Physical Society and member of the Joe Biden science transition team.
Due to its innovative, transgressive, and inclusive character, the 2020 Quantum Battles in Attoscience workshop also gave rise to the opinion piece "Courting Controversy Online" in Physics World (https://iopscience.iop.org/article/10.1088/2058-7058/33/10/21), and was a highlight in the UCL Quantum Annual Report (see https://www.ucl.ac.uk/quantum/news/2020/oct/battle-ready). Furthermore, it was lauded by

prominent members of the attoscience and optics communities as a benchmark for science communication. This is exemplified in the talk by Professor Dejan Milosevic at the CONNECT 2020 in Neum (Bosnia) (https://connect2020.online/2020/08/quantum-battle-in-attoscience-by-dejan_28.html). The three battles led to perspective articles in the European Physical Journal D “Quantum Aspects of Attoscience” and to the media article “Following Three Debates” (see https://www.epj.org/epjd-news/2218-epjd-highlight-quantum-battles-in-attoscience-following-three-debates), which extended and complemented the workshop. The editorial Quantum Aspects of Attoscience highlights the mission behind the Quantum Battles in Attoscience and the Atto Fridays (https://link.springer.com/article/10.1140/epjd/s10053-022-00492-6).
The 2023 edition of the Quantum Battles in Attoscience Workshop has just taken place in a hybrid format, at the University College London and online, from 28 to 30 June 2023, and attracted over 70 onsite participants. We had 14 to 20 participants following them on YouTube daily, and, since the live streaming, there have been hundreds of views on YouTube. The videos are still unlisted, but we will make the edited videos public soon. We have secured perspective articles in Nature Reviews Physics (impact factor 36.27) for the three battles taking place this year. A further opinion piece in Nature Physics is under discussion. This year, we have also introduced a panel discussion on sustainable software development, and tools were shared among all participants. We have also organized a public lecture which attracted UCL students and members of the public interested in quantum mechanics.

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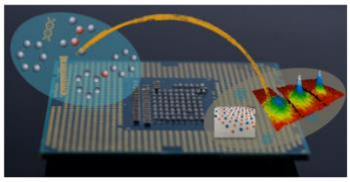

New Frontiers for Simulating Nonequilibrium Many Body Systems in Physics and Chemistry: An Interdisciplinary Response

Location: Sorbonne Université Campus Pierre et Marie Curie, Paris, France
Webpage : https://www.cecam.org/workshop-details/1214
Dates: Jun 28, 2023 - Jun 30, 2023

1 State of the art

The problem of how quantum many-body systems evolve, in particular in the presence of environments, plays a central role in almost all fields of contemporary quantum science. From the excited state dynamics of macromolecules under vibronic interactions, to the design of tomorrow's quantum technologies and nanomachines, understanding the microscopic details of a quantum-many body evolution and the impact of noise (e.g., energy exchange and dissipation) is a critical, interdisciplinary challenge that will be essential for the next generation of advanced functional materials, photocatalysts and quantum devices. A large amount of experimental progress in controlling *almost* coherent quantum many-body dynamics has been made in the last few years (e.g., in the field of ultra-cold atom physics and ultrafast molecular spectroscopy), and in the years to come such setups may serve as quantum simulators for material design and chemistry. However, the last few years have also seen tremendous progress in numerical method development for simulating the evolution of quantum many-body states on classical computers. Important new classical method-advances have, for example, been made in the fields of ultra-cold atom/condensed matter physics and for molecular dynamics embedded in photonic, phononic and vibrational environments. Unfortunately, awareness of these methods has often been restricted to their disciplines of origin. We felt that this is unfortunate, and the critical aim of this workshop was to establish a new interdisciplinary dialogue to unlock the synergies that could enable the development of truly game-changing, cross-community techniques. These synergies, we believed, could lead to powerful new solutions to open questions in the fields of both physics and chemistry, as well as pose new and fruitful questions about existing 'solutions' in these areas. As described, below, this workshop did indeed open such a fruitful dialogue, and has already lead to the identification of critical problems in physics and chemistry where interdisciplinary insights could provide powerful new solutions.

2 Major outcomes

Interdisciplinary aspect: A key outcome of the workshop was to bring entirely different communities together, which led to important cross-field information exchange between a more physics-oriented and a more chemistry-oriented community. This was highlighted as a singularly positive aspect by the attendees, especially by the younger researchers and research students who - thanks to the unique meeting format (see below) - were exposed to a diversity of techniques and problems that could materially impact how and where they chose to pursue their future research projects.
- **The first day** focused on chemistry related methods. In particular there were extensive discussions on MCTDH and its multilayer variant. In the latter case it was discussed how this method is very much related to tree tensor networks. Update schemes for tensor network methods can therefore find important application in the MCTDH community and the other way round. The availability of the "Heidelberg" ML-MCTDH package was brought to the attention of many attendees and will, as an outcome, be now used in a much wider community. Additionally, QM/MM methods were discussed on the first day and how they can faithfully

capture transport dynamics, including quantum aspects in system with mixed discrete electronic and motional degrees of freedom. For the latter problem, exact factorization approaches for potential energy surface dynamics in regimes where the Born-Oppenheimer approximation becomes questionable were discussed. Both methods are relevant to, but were largely unknown, by half of the audience. The day was completed by a general introduction into DFT methods that were introduced to a much broader community.

- **The second day** initiated a discussion on fundamental quantum many-body dynamical effects, in particular related to many-body localization and quantum entanglement. The latter is the key quantity to determine "simulability" using matrix product state approaches. It was in particular highlighted at the workshop that it is an open research question how entanglement can be effectively reduced in open system settings, which could further extend numerical capabilities in the future. DMFT methods have been brought up as another method to study quantum-mechanical many-body dynamics faithfully in a more physics-oriented community. Both of these approaches may now find wider applicability in chemistry-oriented fields, and it was highlighted that the need for efficient 'impurity' solvers for DMFT could be a powerful application for current research on simulating open quantum systems, as discussed on Day 3. Also, variational state ansatz methods (e.g. Jastrow) were introduced, and a key insight was that explicit variational ansätze can still provide a superior method compared to pure machine-learning neural network approaches.

- The final day focused on open system problems, which led to inspiring insights on methods such as HEOM or T-TEDOPA, or many-body process tensor methods. Many ideas such as effective temperature modification by transformation of spectral densities have been brought to the attention of a much wider community. As a general theme it has been become clear that open-system master equations methods can and should be compared to more semi-classical methods that keep larger parts of the bath implicit in the equations of motion.

Quantum computing and machine learning: A general topic of the discussion rounds has been the possible (future) use of quantum computers or machine learning methods in our communities. It has become clear that both approaches are only vaguely known and/or used in practice. The discussion rounds identified the need to start formulating problems in such a form that they can be used with such future technologies. For example, it may can be useful to formulate problems as quantum circuit problems already now, even if the latter are only run with quantum computing emulators for now.

Standards and comparability of methods: see below

3 Community needs

Small group discussions were an essential and unique part of this workshop, enabling participants at all careers stages to learn, propose and debate in a friendly and informal setting. A two-hour discussion session was held each day, with the participants randomly split into four groups of roughly ten people. Each discussion session was focused around topics and questions proposed by the keynote speaker of each day/theme, and summaries of each group's responses to these questions were then presented to the entire audience and discussed in a chaired town-hall format in the amphitheatre. The following key points related to community needs and development were identified:

Standards and benchmarking of numerical methods: how should we - as a broad community with different interests and objectives - set up a relevant set of example models on which each simulation method could be tested in order to compare them *fairly* in terms of efficiency and accuracy (which of course is far from easy and raises many problems). This debate highlighted the need to run codes on common computational architectures and programming languages, but also exposed the problem of the work required to translate existing codes that are often highly optimized in their original language (particularly older C and Frotran codes). How to compare highly parallel and fundamentally serial codes was also flagged as an important consideration for the community. One proposal that was widely supported by the participants was to look more closely at how algorithms/ hardware architectures are tested in computer and data science, such as the various benchmark problems for linear equations, mdense matrix diagonalization, etc.

Open-source community projects and cooperation: as mentioned above, the need to make different codes freely available across communities was seen as an essential 'need' for realizing the interdisciplinary interactions and benefits identified in the workshop. It was proposed that an effective way to do this would be to migrate all software to a common programming language, in order to remove the barriers that arise from having to learn multiple languages, some of which might become obsolete in the mid-future. One fairly recent language that was discussed was the Julia language, which combines the intuitive and intractability of Phython with a similar numerical performance to C and Fortran (and has a very strong and growing support base of high performance packages for numerical and data-based computation). Again, the need for dedicated work and person-hours to do this, as well as centrally hosting/maintaining/supporting/documenting packages that could be used 'off the shelf' was discussed - and the idea of being able to hire software engineers or valorizing PhD work spent largely on code was raised multiple times in the context of grant funding, academic training and career progression. Could working more closely with academic and industrial partners (Google summer of code, for example) in computer science/AI be fruitful?

4 Funding

There was enthusiastic discussion on continuing this interdisciplinary and highly discussion-lead workshop via future CECAM funding applications. The communities brought together multiple disciplines, and after identifying common problems that could be tackled through cross-subject interactions, there was significant discussion about future collaborative networking that could tap funding streams such as COST networks, ITNs or FET-type multi-institutional projects. European-level funding was also discussed, particularly MSC actions for allowing younger researchers the mobility needed to acquire the interdisciplinary expertise and overview needed to unlock the tremendous potential synergies that emerged across this workshop. Also touched upon, by the leading figures in each subject, was the ambitious possibility of obtaining Synergy-level funding to create the fully integrated and professionally supported computational platform for all existing methods that was widely discussed over the three days of the workshop.

5 Will these developments bring societal benefits?

As described in the 'state of the art' section, a fuller understanding of many body quantum dynamics provides a critical pathway to the development of future technologies and materials of wide-ranging societal benefits. The full scope of these benefits was made especially clear in this meeting, as it exposed the long-term ambitions and goals of each community to the other, helping to establish how numerical techniques for, say, cold-atom quantum computation might very well be repurposed for predicting the complex photophysics of molecules that might one day enable low-energy, light-driven catalysis, decarbonizing technologies, or new drug treatments. Reaching these goals requires the development of extremely efficient classical computation techniques, and maybe, in the end, even quantum computing resources. However, the development of the latter is likely to require significant breakthroughs in the former: this workshop's goal of directing disparate approaches and knowledge towards cutting edge classical simulations is thus potentially part of the 'enabling science' for the truly disruptive impacts that are expected from the 'second quantum revolution'. One particularly interesting aspect of developing powerful algorithms was also raised in discussions, one that touches directly on societal and climatic issues. When speaking of 'efficient' algorithms, we often have in mind the amount of description (system size), or accuracy that can be achieved in the fastest time possible or with the fewest computational resources. However, as topically discussed in the context of the vast amount of electricity used in AI and cryptocurrency processing centers, what about the energy efficiency, or heat production, of future algorithms? Being mindful of this issue at this early stage may drive interesting new types of large-scale simulation techniques (or computational platforms) that balance environmental and scientific demands.

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Machine-learned potentials in molecular simulation: best practices and tutorials

Location: Hotel & Palais Strudlhof, Vienna, Austria
Webpage : https://www.cecam.org/workshop-details/1211
Dates: Jul 5, 2023 - Jul 7, 2023

1 State of the art

The workshop focused on the advancements in machine-learned potentials in molecular simulations. Since the seminal work of Behler and Parrinello in 2007 [1], the field of machine learning (ML) in theoretical chemistry has experienced remarkable progress with new developments and applications emerging at an astonishing rate. With new developments and applications emerging rapidly, there have been notable achievements in various aspects of molecular simulations, including the design of molecules and materials [2,3], simulation of molecular and material movements [4-7], and solving the Schrödinger equation [8]. These advancements have been driven by the development of novel descriptors that represent molecules and materials in one, two, and three dimensions [4,5,9] and have led to several developments for accelerated simulations in almost all research fields of chemistry [10-18] and the improvement of the accuracy of simulations with almost no additional costs [19-20].
Due to the fast pace of developments in ML potentials for chemistry, but little consensus on best practices therefore, the goal of this workshop was to bring together people working on different areas of ML and discussing as well as defining best practices, tutorials, and open challenges. Therefore, the participants of the workshop were split into 3 groups, focusing on excited states, biomolecular and extended systems, and unsupervised learning. These areas were defined in advance with participants and participants could assign themselves into one of these groups. the discussions revolved around fundamental concepts, such as "ML basics," where best practices and tutorials were shared on ML training, validation, and data curation—a critical aspect of any ML study.

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2 Major outcomes

The goal of this workshop was to discuss and define best practices, tutorials, and open challenges in machine-learning (ML)-driven simulations of excited states, extended systems (i.e., biomolecular systems and materials), and unsupervised learning. Therefore, working groups were defined and people could discuss within their groups the aforementioned topics as well as between the groups. During the workshop, the participants laid the groundwork for several manuscripts that will continue to evolve over the next few months. These manuscripts will provide comprehensive descriptions of best practices in machine learning, along with concrete tutorials for different types of models, such as ANI, kernel methods, BuRNN, and others.
The group working on biomolecular systems and extended systems established several tutorials that will be shared via github and will be freely available to the scientific community. They further started drafting a manuscript on best practices of ML potentials in this field. The group working on excited states also drafted a manuscript about best practices with a focus on pre-processing of excited-state data, post-processing thereof and surface fitting. In addition, the group will establish a collection of data sets for excited-state learning that will be published soon too. The third group working on unsupervised learning defined best practices that will result in a manuscript as well. They focused on data analysis with techniques like principal component analysis and clustering as well as on generative learning. In addition, the group started some collaborative work on the development of generative models like variational autoencoders for chemical applications.
The expertise from the fields of molecular chemistry and material science contributed to enriching the discussions and led to a dynamic and productive environment, where best practices and tutorials were formulated in each group to make ML more accessible to other chemistry research fields and new entrants in the field. The formulated best practices are planned for future publication in the Living Journal of Computational Molecular Science (LiveCoMS). LiveCoMS, with its living documents that are regularly updated with community input, provided an ideal platform for capturing the evolving nature of the ML field.
The workshop was, to the best of our knowledge, the first of its kind, where participants did not deliver talks but split up into groups to work together. We believe that this is not just a standalone event but served as a stepping stone for future collaborations and ongoing efforts. Via Vevox-sessions, we asked the participants for anonymous feedback. Overall, the workshop was very well received. Some participants mentioned that the workshop could improve by a mixture of talks and discussions to pick especially the younger researchers up and put everyone onto the same level. Some further wishes were for more mixing between the groups, which seemed to be difficult during the workshop. Overall, the workshop was a success, which was not only attributed to the expertise of the participants but also to their willingness to collaborate and share knowledge. The lively discussions and the collective effort showcased the potential of ML in advancing the field of molecular simulations and demonstrated the need for community efforts to define best practices and tutorials. Even in the absence of traditional presentations the less-experienced participants confirmed that they were able to learn a lot from observing and taking part in these discussions.

3 Community needs

During the workshop, participants not only focused on the technical aspects of machine learning-driven simulations, but also recognized the importance of addressing the broader needs of the community.
1. Computational Infrastructure:
One of the key needs identified by the workshop participants is the availability of robust computational infrastructure to support their research endeavors. This includes access to existing codes and libraries that facilitate the implementation of ML algorithms in simulations. Participants highlighted the importance of user-friendly tools and frameworks that enable efficient and scalable computations. One step towards achieving better access was made by delivering tutorials that will be available to the scientific community soon.

2. Networking and Outreach:
Participants emphasized the need for active networking and outreach to foster collaborations with other communities, particularly experimentalists. Establishing effective communication channels between researchers engaged in ML-driven simulations and experimentalists can facilitate the exchange of knowledge, data, and insights, leading to more comprehensive and impactful research outcomes. Furthermore, initiatives aimed at bridging the gap between academia and industry were discussed, as industry partnerships can provide valuable resources, expertise, and real-world applications for ML-driven simulations.
3. Event Organization:
Given the success and positive reception of the workshop, the question arises as to whether a series of workshops on this topic should be considered. Such workshops would provide a platform for researchers to exchange ideas, share advancements, and establish long-term collaborations. The workshop series could feature a balanced combination of talks, discussions, and collaborative working groups to accommodate the needs and preferences of different participants, including younger researchers.

4 Funding

During the meeting, many participants emphasized the need of additional workshops like this and discussed future proposals of workshops. In addition, researchers that met during the workshop discussed joint research projects with the possibility to write proposals. Concrete plans to establish a community consortium to optimally use databases were discussed, together with potentials for funding in the USA (e.g. through MolSSI). More typical funding channels would be the Austrian Science Fund (FWF) for Austria or the Deutsche Forschungsgesellschaft (DFG) for Germany. International projects could be funded by EU-calls. Two participants were already engaging in cross-atlantic funding (US and UK).

5 Will these developments bring societal benefits?

The research topic of the workshop holds significant potential for various societal benefits, ranging from economic advancements to sustainability and health improvements.
By developing tutorials and best practices, also industry can apply our methods and collaborate with researchers to identify further challenges and improve best practices. Especially ML-driven simulations of extended systems are needed to simulate fundamental processes of life, such as photosynthesis. Understanding of such processes could foster the development of artificial photosynthetic materials that could reduce the carbon dioxide levels in the atmosphere. The societal benefit of such a method given the current global warming crisis is obvious.
In addition, the development of best practices on unsupervised learning, i.e., generative modeling, opens avenues for many researchers to delve into this topic and apply it to drug design, which could lead to health benefits. The testing of different generative models by the participants will help the user to select a proper method. The societal impact of current artificial intelligence methodologies is ubiquitous.

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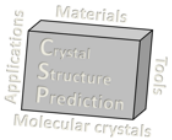

Crystal structure prediction in materials discovery

Location: University of Liverpool
Webpage : https://www.cecam.org/workshop-details/1246
Dates: Jul 10, 2023 - Jul 12, 2023

1 State of the art

Crystal structure prediction (CSP) of inorganic materials is at heart of the discovery and computational design of new materials with targeted properties, such electronic or mechanical properties. Since the different arrangements of atoms can produce different physical properties, it is important to correctly predict crystal structure of the material before evaluating its properties. Similar challenges are faced when predicting the structure of molecular crystals. Specifically, the polymorphism of pharmaceutical molecules, where changes in crystal form can lead to changes in important physical and chemical properties.

The field of crystal structure prediction has made significant progress in recent years, driven by continuous advances in computational methods, increased computing power, and the availability of large databases of experimental and calculated crystal structures.
In both organic and inorganic fields, we see a gradual improvement of the DFT methods providing increasingly more accurate energy calculations. However, these methods have limitations both in the scale of the calculations they can support and, in their suitability, to describe more exotic system. A hierarchical approach to CSP is becoming more common when the output of a simpler but faster model is used in a more expensive but accurate model. Machine learning potentials are a popular solution to do fast and accurate calculations. While they are often system-specific and require reference data from an expensive model, the improvement of the ML models mean that fewer reference data points are required, and the resulting potentials are better at extrapolating and are more transferable.
The CSP presents a number of optimization and combinatorial challenges which means there is a natural engagement with the Computer Science community. On the other side of the scale, there is the "ground truth", the crystal structures observed experimentally, and the engagement with the experimental community is crucial to set up the CSP challenges and to fulfil the main objective of the CSP to drive the design of new materials. By their nature, CSP calculations generate a lot of data that can be used for data mining, statistical analysis, and machine learning algorithms to verify new models, improve our understanding, and identify new physical trends.

2 Major outcomes

This interdisciplinary workshop brought together experts in materials chemistry, *ab initio* methods, machine learning and computer science and facilitated knowledge transfer between different scientific communities working on either organic or inorganic CSP.
Thanks to the active participation of the attendees and lively discussions, we reviewed common challenges across different material classes and discussed the opportunities and best practices in CSP.
The popular questions that were addressed in panel discussions included:

- **The ground truth**. As the structure characterization techniques improve, the complexity of reported crystal structures such as positional and substitutional disorder that previously might have been missed becomes verified. This raises the expectations for CSP to make finer and more accurate predictions and include effects such as temperature and pressure.
- **Energy models**. Hybrid functionals such as PBE0 with the addition of dispersion corrections appear to work well for 90% of test cases for molecular crystals. However, there are systems (nitrogen-rich molecules, co-crystals, systems with proton transfer) for which of-the-shelf approach don't work well. Similarly in inorganic community, in addition to the commonly used GGA (PBE) data, more accurate GGA+U, PBEsol, SCAN and other functionals are used at scale. Machine learning potentials of different levels of complexity and accuracy are expected to be more common in CSP workflows.
- **Success vs failure**. The literature is predominantly reporting successful CSP outcomes. How should negative results in CSP (defined as "prediction did not match the experiment") be reported to raise awareness of method limitations and highlight problematic areas for future development?
- **Overprediction**. CSP runs generate a lot of trial structures with only very small number of those structures observed experimentally as polymorphs. On the one hand, these data are redundant and should be reduced to eliminate "similar" structures. On the other hand, these data contain information on kinetic accessibility, nucleation, crystal growth, defects observed experimentally. The connectivity graphs that represent the CSP data are useful to show the proximity between various local minima.
- **Random vs managed**. Random structure searches are simple to implement and are successful for small systems. To manage combinatorial explosion for larger and more complex systems partitioning of the search space and running sequential algorithms is beneficial.

- **Going beyond energy**. What metrics are seen as indicators for "good" crystal structure prediction, especially for novel materials where no experimental data exists? In molecular systems it is common to plot density-energy maps. Are there other “projections” of the CSP results that might be useful.
- **Thermodynamic stability**. How far above the convex hull should we look for possible hits: 1kT, 35meV/atom, 1kcal/mol or more? The answer depends on the quality of the calculated data and available experimental resources. This is a risk management question to deem which solutions might be considered “experimentally accessible”.
- **Combining CSP with experiment in a single workflow**. CSP can be supplemented with some experimental data and used as a powerful characterization technique to identify the structure of new materials for which partial structural data (e.g., unit cell parameters and symmetry) are available.
- **Blind Test**. In molecular CSP community has encouraged progress in the field by providing a benchmark for evaluating and comparing different CSP methods and encouraging the development of more accurate and reliable algorithms. The downsides include pressure to perform well, the significant time commitment and the environmental impact. More thought is needed on how a similar challenge can be formulated and implemented within the inorganic CSP community.
- **Reducing environmental impact of the calculations**. More focus should be given to training students how to run calculations efficiently – asking the right question and choosing appropriate level of theory to answer the question, using HPC resources carefully (optimal run parameters for the job and the hardware, appropriate code compilation, queue, parallelization, output level etc..).
- **Storing data and distributing the data**. Managing the data continues to be important in the CSP community. With the volume of the data growing exponentially, data management plans are becoming an integral part of research projects.

The workshop gave the opportunity for networking and provided a platform for unique learning experience for students and young researchers.

3 Community needs

The opportunities for applications of fast and accurate ML energy models in combination with advanced search methods were highlighted. Here, there is a need for going from proof-of-concept studies to applying the new tools to a wide range of material targets.
The inherent difficulty in reproducing published data, the need for benchmarking and the long-term need for systematic validation tools were discussed. To address these issues, encourage collaborations and the culture for sharing tools, communities similar to the Materials Project are required.
The organic community is ahead of the inorganic community in some areas such as:

- Using ML potentials for structure optimization.
- Using ML tools in general – new models, such as GPT-type generative models for example, tend to be implemented in the organic field first.
- Dealing with overprediction in CSP and trying to make a better use of the thousands of local minima generated in CSP runs to learn about structure defects, disorder, kinetics, possible crystallization pathways.
- Blind tests are a big thing in the organic community but non-existent in the inorganic.

The networking with other communities, especially synthetic chemists, data scientists, robotics experts, through the events such as CECAM workshops is important to facilitate new interdisciplinary interactions. A closed-loop feedback between the theoretical studies and synthesis and characterization is important to accelerate the discovery of new materials. Such combined computational and experimental workflows should be encouraged through funding specific projects.

4 Funding

The possibility of joint research proposals was not discussed at round table discussions. There were however multiple discussions between the participants of joint research activities and possible collaborative projects during the meeting. The discussions carried out during the workshop have indicated that the development of CSP methods will increase their application in both academia and industry. Thus, the importance of collaborations with industry to apply and continuously improve these tools was highlighted.
While most of the highly ambitious materials research efforts are multi-disciplinary, combining strengths in chemistry, computer science, engineering, etc., it is important that the computational chemistry and molecular modelling communities have the opportunity to advance the methodology independent of its immediate application. Therefore, it is very important that highly technical and specialized, fundamental research efforts are funded.
We expect that new ideas and collaborative projects will emerge, allowing both young and senior members of the CSP communities to apply for funding. The EPSRC, in the UK, is the main source of funding for the development of new initiatives in materials science.

5 Will these developments bring societal benefits?

The discussions carried out during the workshop have indicated that the development of CSP methods will increase their application in both academia and industry. As the main objective of CSP is to identify new functional materials, the main societal benefit will be the improved device performance and the advances in pharmaceutical and chemical industries. The development of better functional materials will bring potential societal benefits such as economic and sustainability benefits that were also highlighted during the workshop as an important factor in prioritizing research directions.
While the advances in drug discovery due to incorporation of computational screening have been demonstrated by the pharmaceutical industry, the computational screening in materials science is much less common and limited to separate examples in different material classes. In this workshop we covered battery materials, thermoelectrics, materials for photo and electrochemistry applications, catalysis and many others.
The progress in computational techniques and increasing available computer power facilitate the use of high-throughput methods for materials design. This in turn contributes to better understanding of structure-property relationship and allows one to optimize material's function. The ability to calculate and verify experimentally the properties promotes an increasing synergistic collaboration between experiment and theory in materials design leading to unique mutual feedback loops between different parts of CSP that accelerate the discovery of new materials.

6 Participant list

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Nanofluidics in physics and biology

Location: CECAM-FR-RA, ENS de Lyon
Webpage : https://www.cecam.org/workshop-details/1217
Dates: Jul 10, 2023 - Jul 13, 2023

1 State of the art

The workshop took place in ENS de Lyon from Monday, July 10 from 2:00 PM and finished on Thursday, July 13 after lunch. The workshop brought together experts from France, Italy, Switzerland, Netherlands, Germany, Spain, Belgium, UK, Israel, Canada, and USA from a broad range of scientific disciplines with the common goal to share the latest developments in the field of nanopore sensing, with focus on nanofluidic, identify the key challenges to overcome, and discuss how future efforts might be concerted to foster experimental and theoretical breakthroughs. In addition to the CECAM funds for this flagship workshop, the costs of the activities have been covered with external financial support from public local and national institutions (ENS de Lyon, CNRS, Région Rhone Alpes, Laboratoire de Physique de l'ENS de Lyon) and private sponsor company such as Imec (Belgium) and Elements SRL (Italy). The sessions comprised of a mixture of invited and contributed talks and two poster sessions presented by the students.
Compared to the previous CECAM flagship workshop held in Trieste, September 2021, this workshop had a large focus on protein translocation under electroosmotic flow (EOF) and memristor systems.
Compared to DNA translocation, protein translocation through nanopore presents at least two challenges, namely: (i) the larger chemical diversity of the 20 amino acids compared to the 4 nucleotides, and (ii) unlike nucleotides, most amino acids are electrically neutral. A large number of the talks on protein translocation touched upon the subjects of protein sensing, sequencing, and fingerprinting of post-translational – a very important contributing factor for diagnosing diseases. Many of the talks discussed electro-osmotic flow (EOF) to drive the proteins through nanochannels and pores.
Another new emerging trend is the ability to create memory systems called memristors using nanofluidics systems. These devices are able to store information and compute basic logical operations with highly confined ionic solutions. The next step will be to integrate a large number of these systems in order to perform neuromorphic computing in an array of nanopore.

Key References

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*[2] P. Robin, T. Emmerich, A. Ismail, A. Niguès, Y. You, G. Nam, A. Keerthi, A. Siria, A. Geim, B. Radha, L. Bocquet, Science, **379**, 161-167 (2023)*

2 Major outcomes

Monday's session started with Prof. C. Chan's talk on post translational modification (PTM) and discussed difficulties in translocation of short protein chains. Other talks in this session by A. Sauciuc discussed use of Machine Learning and deep learning assisted detection of different PTMs. Prof. S. Balme and his group during talk and during poster session presented the work of Amyloid-Beta aggregation in the context of Alzheimer's disease. Prof. U. Keyser talked about forces on DNA-RNA complexes, mentioned about seminal experimental work of late Prof. Golovchenko that were validated by simulation studies. Prof. M. Muthukumar made connection to the nanopore translocation in presence of disorder with old and new theoretical results.

Tuesday's lively sessions had several talks about transport. L. Bocquet talked about ion-water transport, electron transport, novel ideas of ionic computing network and neuromorphic computing. This topic was repeated in di Muccio's talk who talked about memresistors using history dependent conductance of ion channels. I. Bodrenko talked about eDFT for nanopores. Reisner presented a new technique for making parallel nanopores. G. Stan presented computational work on substrate proteins, ATP dependent threading through nanopore and explained the numerical result with "hand-over-hand" model. C. Holm talked about numerical modeling of DNA translocation through nanopores and Antonio Suma presented the latest results from theoretical model and computation about the translocation properties involving the unzipping of DNA and RNA. T. Emmerich talked about memresistive swicthes. J. Behrends demonstrated the use of an Aerolysin pore to differentiate structural isomers of proteins. M. Wanunu discussed translocation of proteins through biological pore. Several speakers during their talks mentioned how they got benefitted by the all-atom simulation results done by A. Aksimentiev. G. Maglia discussed the role of EOF in driving proteins through nanopore.

The highlights of **Wednesday's session** were the talks by A. Meller, one of the early pioneers in the field of nanopore translocation, who talked about novel ideas of combining nanopore with nanochannels with which he demonstrated dual amino acid labeling and single protein particle tracking and C. Dekker demonstrated the electric field driven rotation in molecular motors.

Thursday's session J. Mathe discussed transport of different biomolecules Glysoaminoglycans, Dextran, and sensitivity of the Aerolysin pore in differentiating variants of Hayluronic acid. Mauro Chinappi discussed EOF capture and used M. Muthukumar's theory to explain the experimental results.

In addition to the invited and contributed talks the workshop had continuous lively discussion during the coffee breaks and lunches offered to participants at the ENS Lyon cafeteria, and last but not the least, the workshop dinner. Both the poster sessions held during Monday and Tuesday provided additional opportunities to follow up with the speakers and their group representation at the posters. During Thursday's session all the participants appreciated the usefulness of the workshop. Fabien Montel on behalf of the organizing committee thanked ENS Lyon support staff Ms. Fatiha Bouchneb that was essential for the smooth operation and progression of the workshop.

In the concluding remarks, Fabien Montel on behalf of the organizing committee communicated to the participants that a discussion is in progress for another flagship workshop in continuation of the latest development in nanopore sensing to be hosted in 2025, possibly in Cagliari, Italy.

3 Community needs

The central position of European research groups in the field of Nanofluidics have been demonstrated once again during the conference. A reinforcement of the networking at the European level (through doctoral networks for example) appears to be an important step in order to stabilize this situation. Allowing the access to super computing infrastructure

(equivalent of the one A. Aksimentiev in U. Illinois) remains also a challenge for computational scientists in Europe and should be facilitated.
The need of a regular workshop that bridges computational, theoretical and experimental approaches of the field of nanofluidics was highlighted by all the participants. The rapid development of new simulations methods and experimental systems strengthen the need of frequent discussions between researchers from different communities (physics, chemistry, biology, engineering) in order to lower the energy barrier between highly specialized experts. An increase in the collaboration between experimentalists and computational approaches can be observed during this edition and follows the work of the previous conferences.

4 Funding

Typical funding of the research in this field are based on national research agencies (e.g., ANR, DFG) but also European funding agencies (e.g., ERC). Co-funding between European and US agencies (NSF) should favor in order to create complementarity between Europe and the United States. The need to build a doctoral network around the theme of Nanofluidics appeared clearly during the conference. Funding dedicated to used European and US computing infrastructures should be favored in the coming years.

5 Will these developments bring societal benefits?

The flow of molecules at the nanoscale plays an important role in many biological, chemical and physical processes and have important applications in the near future. The field of nanofluidics as numerous direct applications in crucial domains like energy (development of osmotic energy recovery technologies) and health (sensing of biomolecules, biomarkers, pathogens).
Sequencing of DNA and RNA in the context of medical diagnosis is one of major recent success of the field of nanofluidics. New developments on the sequencing of proteins were at the heart of this edition of the conference. Important technical challenges at the crossroad between experiments and simulations will be an important focus of the research in the field in the coming years.
The building of new energy efficient computing schemes based on a network of nanofluidics systems will be another source of potential impact in the coming years.
Other important applications are offered by the development of biomimetic approaches (based on the nuclear pore complex) for increasing the performance of biomolecule filtration.

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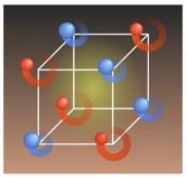

Chiral Phonons in Quantum Materials

Location: CECAM-Lugano, Aula Magna, USI West campus, Lugano, Switzerland
Webpage : https://www.cecam.org/workshop-details/1202
Dates: Jul 17, 2023 - Jul 19, 2023

1 State of the art

In recent years, a rapidly increasing amount of studies has reported novel physical phenomena arising from lattice vibrations that carry angular momentum, leading to the emergence of the field of “chiral phonons”. On the one hand, chiral phonons have been identified in a variety of 2D and 3D materials, emerging from the very nature of the underlying symmetry of the crystal lattice. On the other hand, chiral phonons can be induced and investigated in state-of-the-art pump-probe experiments, extending the field of chiral phonons into the strong-field and non-equilibrium regimes.
However, research on chiral phonons and phonon angular momentum has been developed autonomously, with theory and experiment spanning several different scientific communities, including the spintronics community, the two-dimensional (2D) optoelectronics community, the ultrafast dynamics community, and the thermal transport community. Although the underlying physical mechanisms are all associated with phonon angular momentum, there has been surprisingly little interaction between the different fields. The methodologies and materials systems have mostly been orthogonal, and even the definitions of chiral phonons vary.
Addressing this gap, the inaugural CECAM flagship workshop on Chiral Phonons in Quantum Materials marked a significant step. By assembling prominent researchers from these diverse communities, the workshop fostered the exchange of recent progress and the cultivation of a unified framework for ongoing and future investigations into chiral phonons.

2 Major outcomes

During the workshop, various topics of high interest have emerged throughout the discussions. The topics can be roughly summarized by: i) a common definition of chiral phonons; ii) chiral phono-magnetism; iii) giant thermal Hall responses of chiral phonons; iv) the development of THz laser techniques for high-precision high phonon control.
The usage of the notation of chirality appears to be ambiguous throughout literature, where chiral phonons have become increasingly synonymous with circularly or elliptically polarized phonons. While phonon angular momentum, J, is the fundamental quantity of interest in most cases discussed throughout the workshop, chirality can have additional implications for the type of allowed interactions of phonons with light, electrons, and other quasiparticles beyond angular momentum. This has led to the notation of “truly chiral phonons” and a vivid debate on the influence of symmetries (mirror symmetries, parity, time-reversal) and dimensionality. As a result, it is planned to develop a perspective paper among the workshop participants throughout the upcoming weeks.
The angular momentum of phonons has been discussed as the promising mechanism for tuning magnetism, giving rise to the field of chiral phono-magnetism. A first class of examples concerns the ultrafast demagnetization of magnetic materials. Here, the workshop has brought forward our understanding of how this mechanism takes place on the ultrafast timescale, where the angular momentum from the electronic spin gets transferred into chiral phonons which later decay into a global sample rotation. A second class of examples concerns the transient magnetization of nominally nonmagnetic materials due to laser induced chiral phonons. While a bare ionic effect would lead to a tiny magnetization, measurements in

SrTiO3, KTaO3, and Pb1-xSnxTe show an effect which is at least four orders of magnitude stronger. A third class of examples concerns the ultrafast switching of magnetization in layered structures, where the workshop has seen first promising results on how ferromagnetic thin film can be switched by chiral phonons in the substrate.
Besides a giant magnetization, indications for a giant thermal Hall effect due to chiral phonons were presented. This is motivated by the identification of a giant thermal Hall effect in the pseudogap phase of cuprates, clearly associated with phonons. Also, symmetry makes it likely that the involved phonons develop a handedness, i.e., can be regarded as chiral phonons. Yet, the mechanism that leads to chirality is under debate. Furthermore, the influence of impurities to the thermal Hall effect, as well as the interplay of chiral phonons with (magnetic) impurities has been discussed as the promising path forward.
Several novel experimental methods introduced during the workshop could unlock unique properties of chiral phonons. First, the spontaneous inelastic Raman, X-ray, and photoluminescent side-band scattering revealed the selection rule of photon-phonon and electron-phonon coupling, confirming the angular momentum and non-degeneracy of chiral phonons. Second, time-resolved optical spectroscopy and electron microscopy of stimulated, impulsively generated, or coherently driven chiral phonons have unambiguously demonstrated the coupling between spins and chiral phonons in many ultrafast phenomena, that potentially lead to real applications. Finally, we envision that a combination of multiple probes, including sensitive thermal transport for very low phonon populations, as well as new experimental conditions in extremely low temperatures and high magnetic fields, could potentially lead to more discoveries of chiral phonons and new properties in a wider range of materials to test existing theories.

3 Community needs

On the theory and computational modeling side, chiral phonons are currently mostly discussed on the level of simplified models and selected materials. A general scheme for ab-initio modeling is therefore necessary to make quantitatively accurate predictions about the phenomena arising from chiral phonons. Here, the primary challenges are related to the intrinsic complexity of the problem resulting from: i) the coupling of many degrees of freedom in realistic spin-lattice coupling simulations; ii) the dynamic and non-equilibrium nature of various experiments involving chiral phonons; iii) novel theoretical concepts coupling spin and lattice degrees of freedom which are not present in current ab-initio codes. Developing these aspects would allow the community to investigate novel and exciting ideas discussed throughout the workshop, for example including a modern quantum theory of ferroaxial polarization, exploring quantum phonon fluctuation effects, investigating the application of coherent chiral phonons for non-equilibrium time-reversal breaking quantum materials, and delving into transient multiferroicity with THz drive at a deeper level. As there are different mechanisms for light-induced magnetic fields and optical manipulation, a common theoretical ground of spin-phonon coupling or a classification of the validity regime for different mechanisms becomes necessary.

4 Funding

Due to the novelty of this emerging field, there is not an established funding channel that members of the community focus on, beyond general calls supporting quantum materials research and spintronics that generally fit the scope of chiral-phonon research. During the workshop, members of the community have in particular discussed multinational funding opportunities, and several funding schemes have been identified, primarily collaborations between the national science foundations, including NSF (USA), NSFC (China), DFG (Germany), ISF (Israel), VR (Sweden), and others.

5 Will these developments bring societal benefits?

The field of chiral phonons is still at an early stage. Yet, it shows a potential realization of various novel technological applications. As chiral phonons can be induced by ultrafast laser processes, they provide a fundamentally new direction in the control of magnetic properties, which are at the heart of modern information technology. Specifically, as the experimentally verified magnetic effects due to chiral phonons are significantly larger than expected a few years ago, their potential for replacing strong magnetic fields in selected cases would greatly decrease energy costs compared to state-of-the-art methods that use electric currents to produce magnetic fields.
Another promising direction involves the application of chiral phonons in ultra-sensitive quantum devices. As state-of-the-art SQUID magnetometers are able to detect tiny magnetic fields up to the femto-tesla regime, a detection of single chiral phonon excitations by the means of the phonon angular momentum becomes imaginable. This opens the prospect of detecting fields coupling to ionic degrees of freedom or to electrons which decay into chiral phonons. Throughout the workshop, this idea has been presented on the example of dark-matter detection, posing the challenge of detecting currently unknown forms of matter weakly interacting with conventional matter.

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200 hundred years of Navier-Stokes and turbulences

Location: Les Houches School of Physics
Webpage : https://www.cecam.org/workshop-details/1218
Dates: Jul 31, 2023 - Aug 25, 2023

1 State of the art

Because of their age, the Navier-Stokes equations are often described as "classical", suggesting that there's nothing important left to discover in fluid mechanics, whereas in reality, despite 200 years of active research, the discipline retains an unshakeable youthfulness. On the one hand, because the complexity of the Navier-Stokes equations makes them an evergreen system of study, whose mathematical properties and physical implications are far from fully revealed, particularly in the context of Turbulence, whose first foundations of understanding (based on Kolmogorov's work in 1941) are much more recent than, say, the theory of relativity or quantum mechanics. On the other hand, because the major contemporary issues - such as climate, the environment and ecological transition, public health, etc. - which society must face in the very short term, are inseparable from major new scientific advances in the understanding and modelling of Navier-Stokes Turbulence. In this context, the aim of this school is to provide PhD students, post-docs and young scientists with courses, given by experts working on the fundamental aspects of Navier-Stokes turbulence, reviewing not only the knowledge accumulated over the two centuries of existence of these equations, but also the remaining barriers and open questions in various impacted fields of science that the next generations of scientists will have to explore and deepen in order to respond to tomorrow's major challenges (climate, environment, ecological and energy transitions, etc.) involving fluid turbulence.
The complexity of Navier-Stokes turbulence lies mainly in the nonlinear, non-local nature of the master equations, leading to complex, random, multi-scale, non-equilibrium dynamics, illustrated for example by the famous turbulent energy cascade phenomenon. These already complex dynamics can be further complicated by the presence of walls, global rotation, stratification, natural or forced convection, etc., which generally coexist in real systems. Consequently, the framework of stationary homogeneous isotropic turbulence, which has been the privileged playground of turbulence research in the 20th century, is certainly too restricted, whereas recent advances show that crucial conceptual advances can be made in a more general context, with very important applicative repercussions, whether for the understanding of natural systems or in a technological innovation approach. Sharing these recent advances across a vast interdisciplinary scientific community is therefore of the utmost importance today. This is mandatory in particular from the point of view of numerical simulations. Indeed, because of the high non-linearities of the problem, the effective number of degrees of freedom increases with the Reynolds number of the flow (which quantifies the intensity of the turbulence), to the point that even the direct numerical simulation of a simple systems such as domestic mixer is out of reach of the biggest supercomputers, not to mention the simulation of complex systems such the earth atmosphere and ocean. Simulating such systems therefore requires a deep understanding of the physical processes at small scale (including molecular diffusivity and molecular viscosity) in order to parametrize them in models with reduced degrees of freedom, solvable by our computers. This requires the interconnection of multi-disciplinary fields, including computer science, mathematics, physics as well as the applicative fields (engineering, geo-astro physics, etc.).

2 Major outcomes

The aim of our school was to provide high-level courses on the fundamental aspects of turbulence and the Navier-Stokes equations (whose bicentenary we are celebrating) and their applications. Thus, the school's scientific program covered both the mathematical aspects of the Navier-Stokes equations, their consequences on the description and fundamental modeling of fluid motion, and the practical implications taking into account realistic flow conditions in natural and industrial applications. These different aspects were covered during a 4-week program (from 07/25/2023 to 08/31/2023 at the Ecole de Physique des Houches) for a total of 124 hours of lectures (28 hours per week), plus 12 seminars (3 per week), taking advantage of the thematic diversity among the participants.
Our school welcomed 55 participants, including 33 French and 23 foreigners. The courses were taught (in English) by 18 lecturers (9 French, 9 foreign), each delivering 3 to 5 courses of 1 to 1.5 hours. For greater pedagogical coherence, courses on related themes were grouped together by week, and the courses of each lecturer were grouped together during the same week. The following aspects were covered:
Navier-Stokes: from the maths to the actual fluid
- Mathematical aspects (Vlad Vicol & Edriss Titi)
- Dissipation and singularities (Bérengère Dubrulleà
- Reduction of Navier-Stokes eqs.: LES, POD and other reduced models (Bérengère Podvin & Carlo Cossu)
- Learning approaches (Edriss Titi)

Navier-Stokes and Statistical Physics
- Entropy, cascade and large scales (Joachim Peinke)
- Lagrangian Dynamics and Irreversibility (Gregory Falkovich & Aurore Naso)
- Transition to turbulence (Bjorn Hof)
- Simulations Lattice Boltzman (Ilya Karlin)

Beyond stationary homogeneous turbulence and toward classes of universal principles for a wide range of turbulent flows
- New phenomenology of non-stationary turbulence (Christos Vassilicos)
- Wall turbulence (Alexander Smits)
- Atmospheric Turbulence (Juan Pedro Mellado)
- Turbulence with waves, wave turbulence (Sébastien Galtier & Nicolas Mordant)
- Turbulent Rayleigh-Bénard and Taylor Couette (Herman Clercx)
- Cryogenic turbulence: turbulence without viscosity (Mathieu Gibert)

The program has been designed to ensure coherence between each week's lessons, as well as consistency in the progression of concepts introduced throughout the school.

3 Community needs

Beyond the symbolic aspect of the bicentenary of the Navier-Stokes equations, which initially motivated the organization of a particularly important 4-week school, our school is part of the NCTR (New Challenges in Turbulence Research) bi-national conference cycle, whose last meeting was held in 2021 and whose next edition is already being prepared for 2025. Research in Fluid Mechanics in general and Turbulence in particular is at the dawn of a golden age. Indeed, in spite of its bicentenary, the field is still very young in terms of its understanding, and enormous progresses are constantly been achieved. The present is particularly revolutionary thanks to the advent of learning approaches and other disruptive technologies such as neuro-morphism, which shall lead to unprecedented progresses in metrology and numerical simulations. As a consequence, the state of the art in the field is constantly renewed what requires the community, and all its transdisciplinary components, to meet regularly in such schools to update the collective knowledge. The cycle NCTR is part of this dynamics since 2010 and the next edition (NCTR 7) is already in preparation for 2025.

4 Funding

Possible new sources of funding for future researches in the filed were discussed during the meeting. As a matter of fact, a joint European project, within the ITN (Innovative Training Networks) action is currently in preparation with an expected submission by the end of November 2023.
Other possible fundings can be considered, at different levels (National, European and International). At the national level, this include ANR submissions, but also more ambitious project, in the format of new future PEPR-like calls. At European level, Horizon 2020 offers different possible actions among which ERC Synergy, which is being considered by participants of the meeting. At international level, the possibility of fundings by the Simmon foundation (which must be transdisciplinary and include mathematicians) have been mentioned as well as other smaller actions as for instance Franco Indian projects in the framework of CEFIPRA program.

5 Will these developments bring societal benefits?

The topic of this school, Navier-Stokes equations, is the master equation of the motion of all fluids. The world we live in (starting with the air and water that surround us and the sun that gives us light and heat), as well as the majority of matter in the universe (gases, liquids or plasmas) are fluid. Thus, fluid science is at the heart of most living or natural phenomena on the Earth's surface, of almost all human activities (health, industry, transport) and their impact on climate and the environment on a planetary scale. This discipline conditions our capacity to measure and diagnose flows, model and predict their behavior and dynamics, innovate, and discover new phenomena at all scales. The shift to energy transition, the development of a green, emissions-neutral and innovative industry, the development of sustainable energies, the move towards gentler, safer urban planning and transport that is more respectful of people and the environment, improved diagnosis and decision-making to limit the effects of human activities on climate change and vice versa, improved weather prediction and management of extreme phenomena, advances in medicine, biotechnology, health crisis management, etc., are all inseparable from advances in fluid science in the future.

6 Organizers list

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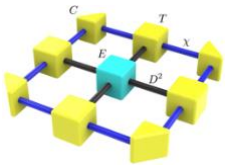

Entanglement and Topology in Strongly Correlated Systems

Location: Centro de Ciencias de Benasque Pedro Pascual, Spain
Webpage : https://www.cecam.org/workshop-details/1223
Dates: Aug 6, 2023 - Aug 19, 2023

1. What were the major topics discussed in the event, and how have they contributed to advancing the state of the art?

The understanding of the rich physics exhibited by strongly correlated quantum systems has seen a rapid development in recent years, driven by a deepened understanding of their underlying entanglement structure. This includes a diverse range of topics: The interplay of symmetries and entanglement which gives rise to diverse symmetry-protected and symmetry-enriched phases, including higher-order symmetries; disorder, thermalization, and many-body localization; new analytical and numerical approaches based on tensor networks, using the entanglement structure of those systems; novel developments in integrability; advances in Quantum Monte Carlo and other simulation methods for entangled quantum systems; the use of machine learning in quantum physics; applications of entanglement in quantum gravity. As planned, those topics have been extensively and successfully discussed during the meeting.
The event took place at the **Centro de Ciencias de Benasque Pedro Pascual** which is a facility of the Spanish scientific system and is open to the entire international scientific community. For our event see: https://www.benasque.org/2023scs/. Our workshop greatly benefited from the infrastructure of the Center with, besides the lecture room, offers houses desk space and very large boards perfect for discussions and collaborative work. This has greatly favored cross-fertilization between all the topics mentioned above, hence contributing to advancing the various fields.

2. What were the primary outcomes of this workshop, including limitations and open questions?

The aim of this two-week meeting was to bring together both specialists and newcomers in the field of entanglement in strongly correlated systems, located at the interface of quantum information and condensed matter. The format of the event consisted of both introductory lectures on the above topics and beyond, as well as specialized talks on current developments in the field. In addition, there has been the possibility for participants to contribute talks, as well as to present posters. During the workshop, many spontaneous informal discussions encouraged by the organizers and announced throughout the day took place. Our plan to have a very rich and collaborative meeting was realized successfully.
The main scientific outcome is twofold: quantum information inspired approaches such as tensor networks for zero and finite temperature properties of strongly correlated systems have already demonstrated their power in solving problems that are out of the range of more standard approaches such as Quantum Monte Carlo, yet there is a lot of room for further developments, hence the invitation of many young participants.

3. What was the take-home message for the participants?

The main take home message was to encourage the younger participants to work in this field and further develop approaches inspired by quantum information. Ample time for discussion sessions has enabled lively interactions between the younger participants (who attended in large numbers) and the more senior and experienced invited speakers. Most of the talk's slides have been collected and are available on the Centre's website https://www.benasque.org/2023scs/ for the participants.

4. Does the outcome(s) of the workshop hold potential for societal benefits?

As usual for fundamental research, the societal benefits are a long-term objective. In the present case, the development of approaches related to Artificial Intelligence to attack the quantum many-body problem is likely to have an impact on better understanding the foundations and potential of methods such as machine learning, with a potential impact on many problems of more direct societal relevance.

5. Are there tangible outcomes of the workshop (e.g., publications, new collaborations, plans for proposal submission, software developments, etc.)?

Collaborations have started during the workshop, and participants are encouraged to mention it in the acknowledgments of their articles.

6. What measures did you take to promote inclusivity (gender, geographical provenance of participants and speakers, career stage, disabilities, etc.)?

We ensured that the program was as balanced as possible regarding gender given the diversity in the field. Besides we have made sure that the announcement was widely through colleagues at ICTP Trieste as well as in India and China, and participants from these countries have been systematically welcome provided they were active in the field of the workshop.

7. Organizers list

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Accelerating Improvements in Density Functional Theory

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1197
Dates: Aug 21, 2023 - Aug 25, 2023

1 State of the art

Density Functional Theory (DFT) is a powerful quantum mechanical approach used in various scientific fields, such as chemistry and materials science. It reduces the computational complexity of the electronic structure problem by replacing the many-electron wavefunction with the electron density as the primary quantity of interest. DFT serves as a computational simulation tool to gain insights into the properties of a wide range of systems, encompassing atoms, molecules, and materials. Its significance is underscored by its extensive utilization on academic high-performance computing systems, where it accounts for approximately one-third of the computational workload. The accuracy of DFT relies on approximations to the exchange-correlation (XC) energy.
This workshop focuses on recent advancements in XC approximations for both ground-state and time-dependent DFT, including meta-generalized-gradient approximations, hybrid and range-separated hybrid functionals, non-collinear magnetism, and dispersion interactions. It delves into methods for constructing XC approximations based on known constraints, such as the adiabatic connection, self-interaction freedom, piecewise linearity, discontinuities, delocalization error, ensembles, asymptotic behavior, integer preference, zero-force theorem, and memory effects. Moreover, it covers developments beyond density and gradients, encompassing conditional probability densities, orbital densities, pair densities, and other related quantities. Efforts to overcome the computational challenges posed by the cubic scaling of KS equations for large systems are explored through orbital-free DFT, linear-scaling algorithms, and stochastic methods. Additionally, the workshop highlights formal developments in DFT alongside related methods like many-body perturbation theory, wavefunction theory, and embedding methods. Finally, this workshop covers the potential of machine learning to expedite DFT calculations and the use of DFT.

2 Major outcomes

The workshop had a clear focus: improvements of DFT and DFT methods. Within this focus many topics, directions and lines of work were covered. This ranged from the formal mathematical basis of DFT, e.g., questions of v-representability, to more applied questions of how to select test sets for parametrizations; from advancing existing methods like tuned hybrids to questions how to principally treat magnetism and noncollinear spin; from discovering and quantifying errors in density functional approximations to ways of their elimination or mitigation; from semiclassical methods to methods based on many-body perturbation theory like ACFD approaches.
The topics discussed spanned an excellent array of diverse and important scientific directions, many of which will become in the near future central in the development of density functional theory:

1. Mathematical aspects on the foundations of DFT and the connection to development of density-functional approximations.
2. New approaches to approximating functionals in KS-DFT and generalized KS-DFT, including (but not limited to) satisfying known exact constraints, analytic and numerical, e.g. piecewise-linearity, flat plane condition, elimination of self-interaction, the

adiabatic connection, emergence of steps and plateaus, theorems on averages of densities.

3. Development of accurate density functionals for observables other than the total energy and the density (in particular, in the context of magnetism).
4. Development and critical evaluation of DFT methods via the connection to wavefunction methods, in particular in the context of strong correlation, where the achievements of many DFT approximations are weak.
5. Development of orbital-free (OF) DFT methods, which will be able to compete in accuracy with KS-DFT, and analysis of the factors that hinder progress in this direction, particularly, accurate description of chemical bonds in OF-DFT.
6. Extension of existing methods in DFT to systems at finite temperature, especially toward applications in the warm dense matter regime.

The role of machine learning (ML) methods in DFT – both in theory development and in applications: will ML just be an advanced fitting procedure producing Blackbox functionals that outperform most of our existing functionals or will ML also give us insights into the physics and chemistry of the problem. Furthermore, founding a commonality in how ML approaches should be critiqued and analyzed for robustness is desirable.

3 Community needs

This workshop has highlighted the importance of such events in the future. Its success, in its unique format, was consensus among participants. A key feature was ample time for discussions, promoting meaningful interactions. Unlike many meetings, talks were followed by substantial question time. Designated time for formal discussions after each session allowed for in-depth conversations.

Another unique feature of this meeting was in achieving the balance between focusing the topic versus diversity of themes and top-notch speakers. This way we could not only learn about various aspects of DFT but relations between topics that, at first, seemed not much related became visible. This is a prerequisite for cross-fertilization across subfields. According to many participants this was what made the meeting highly valuable.

Two areas for improvement emerged: 1) Encouraging broader participation in discussions, especially among junior attendees. Offering rewards for active participation such as a small prize for the best questions. 2) Ensuring gender equality among the participants was raised in the feedback. This is an important point, which we addressed in the organization of this meeting by inviting a diverse group of invited speakers in terms of gender, seniority, and topical focus which was appreciated by the participants.

The continued need for CECAM workshops on DFT theory development is evident. Previous successful events (2011, 2015, 2017, 2019 and 2023) and oversubscribed workshops mirror the growing community. To strengthen DFT-theory workshops with CECAM, each workshop could emphasize different sub-topics. This approach has already proven successful here where we focussed on machine learning and warm dense matter topics. This approach fosters networking and outreach to neighboring communities, such as wave function methods, many-body perturbation theory, and ab-initio molecular dynamics.

4 Funding

The feedback we received from numerous participants emphasizes the collegial atmosphere and collaborative nature of the workshop. This was made possible by meticulously planning the workshop schedule, allowing ample time for discussions following presentations, and incorporating moderated discussion sessions at the end of each session. Although explicit plans for formulating joint research proposals were not explicitly discussed during the workshop, vibrant and highly productive discussions unfolded among researchers at all career stages. These discussions have generated several promising research directions, which are summarized above as major outcomes. We are confident that the results of this workshop will materialize as collaborative projects and potential research proposals involving some of the workshop participants and their closely aligned scientific communities in the near future. These endeavors will likely seek funding through common national and European channels.

5 Will these developments bring societal benefits?

Our workshop and its future developments facilitate economic and societal benefits in various ways. It contributes to achieving economic benefits by enabling advanced research and development: Improved XC approximations in DFT can lead to more accurate and efficient computational simulations, reducing the cost and time required for materials discovery and development. This can benefit industries such as pharmaceuticals, materials science, and nanotechnology. Similarly, enhancements in DFT methods can optimize the utilization of high-performance computing resources, potentially reducing energy consumption and operational costs for academic and industrial users of supercomputers.
Furthermore, our workshop contributes to achieving sustainability benefits. Accurate DFT calculations can facilitate the discovery of new materials with enhanced properties, potentially leading to the development of more sustainable and environmentally friendly materials for applications in renewable energy, energy storage, and pollution control. Similarly, by predicting material properties and behaviors through simulations, DFT can reduce the need for extensive experimental trials, minimizing waste generation and resource consumption in research and development processes.
Finally, our workshop contributes to enabling health benefits through fundamental research. Improved DFT methods can aid in the discovery of new pharmaceutical compounds and their interactions with biological systems, potentially accelerating the development of novel drugs and therapies for various diseases. Likewise, DFT can contribute to the understanding of complex biological systems, providing insights into molecular structures and interactions that are crucial for advancements in health and medical research.

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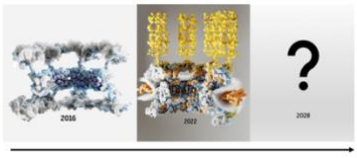

Macromolecular complexes: from ab initio and integrative modelling to functional dynamics

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1204
Dates: Sep 5, 2023 - Sep 8, 2023

1 State of the art

The intersection of recent breakthroughs in protein structure prediction (1), steadily advances in multiscale molecular simulations of biological systems (2) and continuous progresses in data-intensive experimental characterization of protein complexes (e.g., cryo-electron microscopy (3) and mass spectrometry (4)) has allowed for the investigation of large macromolecular protein assemblies with unprecedented accuracy down to the atomistic scale (5-6). This conjuncture has opened incredible possibilities to study the mechanistic details of important cellular machineries shifting the established paradigm in structural biology from “one structure - one function” to the realization that a vast conformational landscape determines instead biological function (7,8) . At the same time, however, the recent progress raises questions on the limitations of the different approaches, and on the extent to which it is possible to utilize these techniques without falling into overinterpretation pitfalls (9). Amongst those, just to name a few, are the ability of predicted protein structures to provide information on protein conformational flexibility; the possibility to correctly predict protein-protein interactions (10), specifically in the case of flexible or unstructured protein regions; the accuracy of molecular mechanics force fields at different resolutions (11); or the relevance of *in vitro* high-resolution structures in comparison with low-resolution *in situ* structures obtained using cryo-electron tomography (12).

In this context, community-wide assessments are gaining even more importance (10), and methodological developments will be key to address and overcome the key limitations of current computational methods. To address this problem, blending expertises from the experimental and theoretical backgrounds, the workshop will extensively focus on how to investigate dynamical and functional aspects of large macromolecular complexes by integrating *ab initio* or integrative modeling approaches with molecular dynamics simulations at different scales. We will discuss the current state-of-the-art in the field, contributing to forecast and possibly foster possible developments and breakthroughs over the next 3-5 years.

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2 Major outcomes

This workshop has brought together experimental, theoretical and computational experts from three distinct but interconnected fields: (i) *ab initio* modelling of protein complexes, (ii) integrative modelling and (iii) dynamical studies of protein complexes' function at different scales. A goal of this workshop was to provide the community with a clear understanding of the possibilities and limitations of current methodologies, which has been greatly fulfilled.

The workshop presented the current advances in structural modelling, particularly, focusing on the recent machine learning tools and how to use them to model macroscale biological systems, such as entire organelles and/or minimal cells. Many questions arose and wide discussion was given on how to tackle the cases where these tools fail, such as for some membrane proteins, intrinsically disordered proteins or when sequence homologous are rare.

Integrative modelling tools mostly harnessed the recent progress in cryo-electron microscopy ranging from high-resolution atomistic refinement to inferring conformational heterogeneous landscapes, some of which have recently been extended to *in situ* tomographic data. However,

the participants concluded that the combination of simulations and machine learning with cryo-electron microscopy and tomography can still be greatly improved, in particular, to provide complexes for multiscale simulations.
How large and long can molecular simulations reach was a main topic of the workshop. Several groups showed recent progress on simulating systems with hundreds of millions of particles. Researchers discussed how to equilibrate these systems and deal with the huge amounts of computational resources required, including advances in hardware for memory and node communication capabilities. A key issue is that there is an inverse relation between the size of the system and how long one can simulate for. The workshop had a good balance between methods that used coarse-grained or atomistic enhanced sampling simulations, which addressed this issue from different perspectives.
All-in-all, the workshop was a stepping stone twoards bridging the gap between the different fields, enabling researchers to discuss and interact by viewing the problems from different angles, and setting the stage for the next breakthroughs in modelling and simulating macromolecular systems.

3 Community needs

This workshop highlighted the need to bring together the different requirements of communities working on molecular simulation and those developing new tools based on emerging ML approaches. While the computational infrastructure is shared between the two fields and is mainly based on cutting-edge GPU-based clusters, more development and effort are needed to share data to allow training of new models and architectures to bring for instance a dynamic dimension to the development of ML-based codes for protein structure prediction. In this context, it was evident that occasions like this workshop are beneficial to foster this communication and establish new networks to facilitate the development of new hybrid approaches. Therefore, we hope that CECAM will pay much attention in the future to this kind of workshops and will promote their organization for the steadily progress of studies in this field. Of note, a similar workshop, but dedicated to a much larger audience and on a bi-annual basis, is now scheduled under the umbrella of the European Molecular Biology Orgnaization (EMBO): "Computational Structural Biology". We suggest to run this CECAM workshop in altenate years with respect to the EMBO one.

4 Funding

Besides funding provided by CECAM we were able to get a SNSF grant for supporting conferences for a total of 15000 CHF. This grant was mainly used to cover the accomodation and flight tickets of international invited speakers, which for this conferences were a significant number. For the future in case another similar proposal will be submitted, funding could be found from journals specilized in this field (e.g. ACS publications) or companies and startups emerging in the field of AI-oriented research (e.g. NVIDIA, Acellera,...).

5 Will these developments bring societal benefits?

The methods presented and discussed during this workshop have direct application for understanding fundamental biology but by reflection methods can be powerful for the development of therapeutic solutions for several diseases. Whether academica will play a role in these developments or if, alternatively, they will be completely carried out by big pharma company or by recent spin off of large AI-labs (e.g. DeepMind) remains to be seen. Overall, however, it is clear that AI-based methods, often in combination with "good old physics" represent a powerful technique to address long-standing problems in drug-design. In particular, the relatively limited computational costs of AI-based methods once the network is trained are very appealing. A major hurdle, however, is the limited amount of information (data)

on which to train the network, since only few ligand-bound X-ray and cryo-EM structures are deposited in the pdb. To this end, the community of this CECAM workshop supports the continuous efforts in blind evaluation of AI-based structural tools, in programs such as CASP, CAPRI or CAMEO.

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Taly, Antoine - CNRS, France
Tang, Wai Shing - Flatiron Institute, United States
Tempkin, Jeremy - Lawrence Livermore National Laboratory, United States
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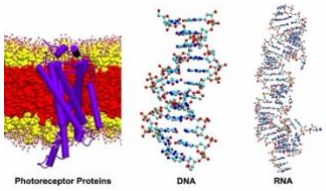

Multiscale simulation of photoresponsive biological systems

Location: CECAM-ISR
Webpage : https://www.cecam.org/workshop-details/1234
Dates: Sep 10, 2023 - Sep 13, 2023

1. What were the major topics discussed in the event, and how have they contributed to advancing the state of the art?

The main topic of the workshop was how to describe light absorption and the consequent reaction in biomolecules. Such photochemical reactions play a crucial role in almost all domains of life including eukaryotes, archaea and bacteria. Examples of light-responsive molecules are photoreceptor proteins and nucleic acids. The workshop also included biomolecules which were modified or altered to be light-responsive, like in the talk by Jonathan Church where an azobenzene derivative was added to tubulin. A common feature of the molecules is that they contain conjugated double bonds that are responsible for their light sensitivity. During the workshop several applications were presented were molecules where undergoing structural changes upon excitation (for example, the presentation by Massimo Olivucci) or doing energy transfer (for example the talk by Ville Kaila). The talks were complemented by report on method development. One aspect was to introduce new electronic structure methods to describe excited state processes more efficiently. To this end Cheol Ho Choi presented the MRSF-TDDFT method which was in close agreement to popular CASPT2 method. Another important topic was the development and application of polarizable embedding, which was presented by William Glover.

2. What were the primary outcomes of this workshop, including limitations and open questions?

The talks at the workshop have shown that simulation of biomolecules have several limitations .They concern the size of the chromophores which can be described using current methods. New alternatives were identified at the workshop. One was the MRSF-TDDFT by Cheol Ho Choi and another one was the use of semi-empirical methods as presented by Elisa Pieri. Also the preparation of the computational models have several pitfalls. This includes the correct protonation states of titratable residues, an example was given by Laura Pedraza Gonzalez. The synergetic use of simulations and experiments was demonstrated by Michael Reppert. He has reported on the spectral tuning of chlorophyll containing proteins using protein mutations. The experimental design was driven by simulations, with the experimental outcome providing feedback to improve the simulations.
New methods to include polarizable embedding were presented by Tomasz Wesolowski and William Glover. The former presented frozen density approaches while the latter has shown the use of polarizable force fields.

3. What was the take-home message for the participants?

The participants have seen state of the art simulations of photochemical reactions in biomolecules. They learned about the new methods to describe excited states and also the improved embeddings of chromophores in different environments.

4. Does the outcome(s) of the workshop hold potential for societal benefits?

Sun light is an important source of energy on earth. Many organisms have evolved to utilize it for energy or signaling purposes. If we understand how to design such molecules and tune their properties, new biotechnological applications will become available.

5. Are there tangible outcomes of the workshop (e.g., publications, new collaborations, plans for proposal submission, software developments, etc.)?

We have proposed to have a joint publication after the workshop, but the participants didn't show enough enthusiasm. However, several participants have made plans for joint collaborations, proposals and follow up meetings.

6. What measures did you take to promote inclusivity (gender, geographical provenance of participants and speakers, career stage, disabilities, etc.)?

The workshop included participants from Europe, Asia and the US. We paid attention to gender balance and had similar number of female and male speakers. Moreover, the speakers were from different stages, ranging from assistant professors to full professor, who are well established leaders in the field.

7. Participant list

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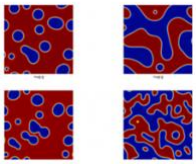

Innovations in fractional calculus and applications to functional and biological materials

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1198
Dates: Sep 13, 2023 - Sep 15, 2023

1 State of the art

Fractional partial differential equations (FPDEs) are emerging as a powerful tool for modeling challenging multiscale phenomena including microstructure in materials, overlapping microscopic and macroscopic scales, anomalous transport, and long-range time memory or spatial interactions. Furthermore, fractional calculus is an excellent framework for modelling nonconventional fractal and non-local media, opening valuable prospects on future engineered materials. Compared to integer-order PDEs, the fractional order of the derivatives in FPDEs may be a function of space and time or even a distribution, opening up great opportunities for modeling and simulation of multi-physics phenomena, e.g., seamless transition from wave propagation to diffusion, or from local to non-local dynamics. In addition, data-driven fractional differential operators may be constructed to fit data from a particular experiment or specific phenomenon, including the effect of uncertainties, in which the fractional orders are determined directly from the data, and introducing nonlinearities leading to more complex operators, with one or more fractional orders, capable to model less typical phenomena (such as, for instance, wave propagation in heterogeneous systems). Similarly, in imaging applications the variable and even distributed fractional order that may change in space offer great flexibility that can be used to suppress noise while preserving edge sharpness.
In short, FPDEs lead to a paradigm shift, according to which data-driven fractional operators may be constructed to model a specific phenomenon instead of the current practice of tweaking free parameters that multiply pre-set integer-order differential operators. Also important is that the misspecification of physical models using integer order derivatives leads to a variable coefficient fit (struggling to fit the data at each location, for example) whereas it was shown in the literature that the “correct” fractional order model can fit all the data with a constant coefficient model. The main reasons that FPDE modeling has not been used extensively so far is that FPDEs are non-unique and that they are quite expensive to solve numerically as they typically generate dense linear algebraic systems due to the nonlocality of fractional differential operators. Furthermore, FPDEs present additional mathematical and numerical difficulties, which are not encountered in the context of integer-order PDEs.

This workshop focused on the use of fractional calculus in different areas of materials, addressing their multiscale structure. We invited researchers who work on multiscale modeling of soft and hard materials as well as applied mathematicians who have made significant progress in advancing the fundamentals of FPDEs.

2 Major outcomes

The workshop was a comprehensive exploration of the wide-ranging applications of fractional calculus, particularly in the intricate modeling of complex fluids and soft solids. Central to the discussions were the innovative constitutive laws founded upon fractional derivatives. These laws, pioneered by researchers in the field, offer a unique perspective on material behavior, exemplified vividly by commonplace items like soft yogurt and salt water taffy.

Throughout the sessions, speakers illuminated the expansive reach of fractional calculus across diverse domains. From the intricacies of electrochemistry to the complexities of robotics, examples abounded, showcasing the adaptability and utility of fractional calculus in addressing real-world challenges.

One notable area of focus was nonlocal elasticity, where fractional models provide valuable insights into material responses that defy conventional analysis. Additionally, the fabrication of fractional capacitors emerged as a tangible application with significant technological implications, promising advancements in various fields, from consumer electronics to renewable energy systems.

The workshop also delved into the mathematical underpinnings of fractional calculus, exploring novel concepts and methodologies for efficiently solving fractional partial differential equations. Discussions centered on developing robust solvers capable of handling the intricacies of fractional material laws, paving the way for more accurate simulations and predictive modeling in complex systems.

As the workshop progressed, attention turned to the fascinating realm of long-range dependent motion, where fractional calculus plays a pivotal role in unraveling phenomena characterized by intricate temporal and spatial correlations. This exploration led to insights into the interconnectedness between complexity theory and fractional calculus, highlighting how the latter provides valuable tools for understanding and navigating complex systems.

The culminating sessions delved into the fundamental properties of general fractional integrals and derivatives, shedding light on the theoretical underpinnings that underlie the practical applications discussed throughout the workshop. These discussions not only deepened our understanding of fractional calculus but also underscored its significance as a powerful mathematical framework with far-reaching implications across diverse disciplines.

In essence, the workshop provided a panoramic view of the current research landscape in fractional calculus, showcasing its profound impact on our understanding of complex phenomena and its transformative potential in tackling pressing challenges across science and engineering.

3 Community needs

It is obvious, that functional materials is a topic that is particularly suited for fractional modeling, but at the present time very few groups in the world are pursuing such research. Fractional calculus is as expressive as neural networks and there is a clear need for combining the two areas to simplify the data-driven modeling required for discovering the complex constitutive laws governing functional materials. Further work is also required both on the experimental side as well as on the theoretical side. In this workshop, presenters showcased the physical realization of fractional capacitors and their enhanced functionality compared to their integer counterparts. More research is required on this front to exploit the unique characteristics of fractional modeling, e.g., frequency dependent damping, for materials in applications such as smart actuators and fractional controllers. Creating experimental databases would be very useful, like the MADE data base created by the geophysics community, which has greatly accelerated modeling in porous media. The Macrodispersion Experiment (MADE) is a

significant research project focused on studying porous media, specifically related to groundwater movement and solute transport. This experiment was conducted at the Columbus Air Force Base in Mississippi, and it has been a crucial site for understanding how solutes move through highly heterogeneous aquifers. Similarly, more theoretical work is required to establish a vector fractional calculus that is universally acceptable and can be easily computable. The recent theoretical advanceson the rigor of the general derivatives is a big step forwards towards unifying the various definitions of fractional derivatives but the problem of establishing multi-dimensional fractional operators remains open

4 Funding

In terms of initiatives, given that there is relatively little activity on fractional modeling in USA, apart from the successful ARO MURI led by Karniadakis, which has ended, it would be beneficial to create funding mechanisms for international collaborations. For example, Igor Podlubny in his talk suggested the following collaboration on international projects:
* EU projects (Horizon, ERC, COST, ...) with US participation;
* Large multi-university USA-EU projects (cross Atlantic projects);
* Bilateral and multilateral projects under various schemes;
* Educational projects and efforts (education is important for knowledge dissemination).

5 Will these developments bring societal benefits?

The societal benefits of the workshop on fractional calculus are multifaceted and far-reaching, touching upon various aspects of technological advancement, scientific understanding, and practical applications. Here are some key societal benefits:

1. **Technological Innovation**: By exploring the applications of fractional calculus in fields such as robotics, electronics, and materials science, which can lead to the development of advanced materials, more efficient electronic devices, and sophisticated robotic systems, ultimately enhancing productivity and quality of life.
2. **Healthcare Advances**: Understanding complex fluids and soft solids is crucial in biomedical engineering and healthcare. Fractional calculus can be applied to modeling biological tissues, drug delivery systems, and medical devices.
3. **Environmental Impact**: The workshop's focus on efficient solvers for fractional partial differential equations can have implications for environmental modeling and simulation. Better predictive models for complex environmental systems can aid in environmental monitoring, pollution control, and climate change mitigation efforts.
4. **Economic Growth**: The insights gained from the workshop can drive economic growth through the development of new technologies and industries. Fractional calculus-based innovations have the potential to create new markets, generate employment opportunities, and stimulate economic activity in sectors ranging from advanced manufacturing to healthcare.
5. **Sustainability**: Fractional calculus-based approaches can contribute to sustainability efforts by optimizing resource utilization, improving energy efficiency, and reducing waste in various industries. By promoting the development of sustainable technologies and practices, the workshop supports global efforts towards a more sustainable future.

Overall, the societal benefits of the workshop on fractional calculus extend across multiple domains, from technological innovation and healthcare to environmental sustainability and global collaboration. By advancing our understanding of complex systems and fostering interdisciplinary collaboration, the workshop contributes to addressing pressing societal challenges and driving positive societal change.

6 Participant list

Organisers

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FAIR and TRUE Data Processing for Soft Matter Simulations

Location: CECAM-DE-SMSM
Webpage : https://www.cecam.org/workshop-details/1228
Dates: Sep 25, 2023 - Sep 27, 2023

1 State of the art

The emergence of big-data-driven techniques as a fundamental paradigm of science has forced the evaluation of the way that researchers manage, document, and share their data [1]. As a result, a variety of domain-specific projects have developed innovative tools for ensuring FAIR--Findable, Accessible, Interoperable, Reusable--or TRUE--Transparent, Reproducible, Usable by others, Extensible--data management [2]. For example, the Novel Materials Discovery (NOMAD) Laboratory is a user-driven platform for sharing and exploiting computational materials science data, with a focus on data from Ab-initio calculations [3]. In practice, 4 main challenges, known as the 4V's of big data, arise when developing data management procedures: volume (the amount of data), variety (the heterogeneity of form and meaning of data), velocity (the rate at which data may change or new data arrive) and veracity (the uncertainty of data quality). In contrast to Ab-initio data, the data generated by soft matter simulations (e.g., atomistic molecular dynamics simulations and multiscale modeling techniques) pose a particular challenge, due primarily to issues associated with the first 2 V's. To address reproducibility of soft matter simulations, Cummings, McCabe, and coworkers have developed the Molecular Simulation Design Framework (MoSDeF), an open-source Python software stack that enables facile use of multiple open-source molecular simulation engines, while at the same time ensuring maximum reproducibility [4, 5]. This suite provides support for constructing topologies and configurations, implementing and saving force fields, and generating simulation input files for popular molecular simulation software. In this way, researchers can implement complex simulation workflows in a fully scriptable fashion that is maximally reproducible [6].
In the context of accessibility and data sharing, various communities have developed niche repositories and management tools. Recently, FAIRmat--a consortium of the German research-data infrastructure (NFDI)--was formed to continue to raise awareness and acceptance of FAIR data practices [7]. One of the primary tasks of FAIRmat is to extend the NOMAD infrastructure to a wide variety of materials science data, including data from soft matter simulations. Additionally, FAIRmat aims to assist the community in advancing metadata schemas and ontologies, enabling efficient exchange of FAIR research data and big-data analyses that aim to revolutionize the development of novel materials.
There are a number of additional recent developments in the community that have come to light throughout the planning of this workshop. In the context of biomolecular simulations, the Bioexcel consortium (https://bioexcel.eu) has already been active for a number of years, developing both data infrastructure (e.g., the MDDB repository - https://mddbr.eu/), and also practical tools for setting up and running biomolecular simulation workflows in a more systematic and reproducible fashion. A more general workflow manager for molecular simulation tasks, signac-flow (https://github.com/glotzerlab/signac-flow), developed by the Glotzer, provides an extremely valuable tool for deploying large-scale or high-throughput simulations. This tool provides a foundation to build more rigorous data provenance standards within the molecular dynamics community in the future. OpenKim [8] is a repository that formalizes the storage of force fields, and has recently begun to develop support for bonded force fields. Optimade [9] represents a successful collaboration within the materials science community for standardizing search and storage of materials science data on repositories. Finally, a recent study has developed software, MDVerse [10], to scrape data from popular reposotories, e.g., Zenodo, to identify potential molecular dynamics simulation for futher analysis or re-use.

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2 Major outcomes

This flagship workshop brought together a diverse group of people within the molecular dynamics (MD) community: members of FAIR-data (or similar) consortia, developers of MD simulation engines, university or institutional data stewards, HPC resource managers, and researchers in the field who are particularly interested in the development of FAIR data standards.
As one of the first workshops of its kind within this community, this event was designed to be discussion focused. In addition to the invited talks and associated Q&A sessions, 5 distinct round-table discussions were held, including a final wrap-up discussion to brainstorm how to continue discussion and collaboration within the community.
The major outcomes of these talks and discussions can be organized into 5 categories:

1. Data provenance strategies for MD sims

(a) How to incentivise researchers to use workflow tools?

- Overall there is a lack of consensus on how to approach this issue. On the one hand, there is a call for journals to implement some sort of standards for simulation studies, however, there is doubt whether this will be adopted or if it can be effective in the end. However, it is clear that as reviewers we can (and should!) try to suggest that certain data standards are met.
- There is a call for educational tools (tutorials, summer schools, etc.) that will encourage and enable the younger generation of scientists to do better in this context. The FAIR-data-type consortia and software projects are already leading the way in this regard, with an enormous amount of progress in the last 5 years.
- There is a call for community-wide standards to be developed. It was proposed that an association is formed to formalize this process.

(b) Minimal ingredients for MD simulation provenance?

- While it was beyond the scope of this workshop to reach a consensus to this question, it did become clear that we should distinguish between different levels of reproducibility. It was agreed that numerical reproducibility is likely too ambitious in nearly all practical examples. However, statistical reproducibility should be strived for,

e.g., when researchers gain access to the original simulation data and attempt to reproduce a result using the same software package. At the same time, it is also useful to consider a lower bar of reproducibility, where the **most important** "normalized metadata" --- i.e., metadata whose meaning is well-defined, independent from any particular software package --- is made available for the community to perform metaanalyses, design high-throughput studies, or (eventually) build machine-learning models.

2. Storage of simulation (meta)data

(a) Standards for metadata

- Perhaps one of the most important tasks identified is to signficantly improve and extend the standards for simulation metadata. Projects like the NOMAD software developed by the FAIRmat consortia and the MOSDEF suite of simulation tools have already begun to develop many schemas for particular subsets of simulation metadata. However, it is important that this development does not become too biased towards particular projects. The development of a community-driven schema project, external to any particular software or file format, would assist substantially in this task.

(b) Findability of MD sims.

- This has been identified as a major task for future development. Unlike single structures from, e.g., DFT calculations, which can be easily identified by chemical formula, symmetry, or material type, the variety and complexity of systems studied with MD simulation presents a particular challenge for findability. Brainstorming during the workshop helped to identify some potential avenues, including the development of taxonomies, or even ontologies for systematic classification of simulations. However, there is clearly much work to be done in this direction.

(c) Data Quality standards?

- This is another topic that caused some disagreement between the attendees. On the one hand, there is some concern that restricting data that is stored in repositories creates larger hurdles for researchers to use such tools, disincentivising them from adopting FAIR-data practices. On the other hand, there is some concern about "incorrect" data being shared. A balance or compromise must be made here, e.g., storing metadata that expert users can utilize to ignore simulations that they deem "unfit". Additionally, there is no reason that every repository has to function by the same set of guildines. Sharing metadata schemas is a much more important concern in this respect.

3. Interoperability of simulations engines

(a) What level of interoperability are we actually talking about?

- See "1(b) Minimal ingredients for MD simulation provenance"

(b) Need to develop community standards

- See "2(a) Standards for metadata" above.

4. Data structures for edge cases

(a) Support for non-vanilla MD methods

- Through initial discussion, it was apparent that not everyone had a good idea of what "edge case" meant, and why it might be useful to consider these. Although one approach to creating metadata schemas is to start with the simplest case (e.g., vanilla MD) and then build out from there, it can also be very useful to consider some representative set of more complicated cases, to help design a more general framework from the beginning. From the discussions, a few key aspects of system and metadata storage emerged that should be considered in developing data structures and schemas. In particular, standardized schemas should allow for variable system sizes and particle identities as a function of the trajectory.
- Another specific question that arose was whether molecular dynamics and monte carlo should be considered within the same structure/schema. Additionally, multi-resolution simulations such as QM/MM or AdRes require significant thought in the development of consistent metadata structures. Again, it would be extremely benefitial to the community to create an external (i.e., not linked to any particular group, institute, or software package) associate that meets regularly and democratically develops

metadata schemas for the community. (See also 5(b) and (c) for suggestions for ongoing developments / collaborations).

(b) Support for coarse-grained models

- The discussion here mirrors 4(a) in a lot of ways. However, it is clear that in many cases the field has been sloppy when dealing with coarse-grained models within many established software packages, and the need for development of rigorous and consistent coarse-grained metadata schemas and data structures should be a priority.

5. Overarching topics

(a) Professional development

- A serious concern that arose dealt with the subject of professional development for students or postdocs working on software- or data-infrastructure-focused projects. Because there is currently a lack of incentives within the academic community for such projects, which may not produce as many publications as a scientific-research-focused project, students may be left with less clear career paths within the academic realm. Data research infrastructure will clearly continue to be an important topic in the future, and it may be necessary to carve more well-defined acedemic paths for the young researchers who are developing expertise in this area.

(b) Reoccurring meetings

- At the end of the workshop, the organization of future similar meethings was discussed. It was decided that in the short terms smaller virtual follow-up / check-in meetings should be held, in addition to established collaborations (see next topic below). Additionally, a similar in-person meeting should be held in a year or two, once some tangible progress has been made. Because this type of meeting is necessarily highly international, to minimize the environmental impact of travel, it will be considered to try to organize such a meeting within a special focus session of some other bigger conference which many participants might be interested in attending anyway. This would also help visibility within the community.

(c) Permanent hack-a-thon / collaborations

- It was decided that we should try to continue discussing in the coming months and attempt to establish well-defined collaboorations, especially between the complimentary software projects being represented. There is already a Slack group that was set up for this workshop, which we will use as an initial platform for inter-project communication.

3 Community needs

1. Computational Infrastructure

- A major relevant topic that arose during the workshop was that there is currently no way of easily sharing large data sets (e.g., trajectories). One proposal was to keep storage local, but allow external researchers to run (reasonably small) analysis remotely. However, there is no current model / practical approach to this, since it is not possible to directly charge for the used cluster resources. An alternative is to go to Google or Amazon, but this is not ideal because then they take ownership of data. Potentially this could be solved through a coallition of HPC centers that somehow enables exchange of computing debts. This topic requires much more detailed discussions and was out of scope of this workshop.

2. Networking

- This workshop provides a foundation for future networking within the community. It is important that we continue to build this network, through dissemination of the outcomes of this workshop and by holding regular events. Please also see sections 1(a) and 5(c) of "Major Outcomes" for specifics discussed at the workshop.

3. Event Organization

- It is essential that the community holds regular meetings regarding data infrastructure in order to begin to converge on some standards, especially for metadata storage. Please see section 5(b) of "Major Outcomes" for specifics discussed at the workshop.

4 Funding

1. Event Organization

- This is typically achieved either through a CECAM node and/or by pooling resources from various 3rd party grants, e.g., from local collaborative research centers. However, these sources are rather unknown and can be inconsistent.
- There is a major difficulty related to the limitations of most funding for events. For example, the present workshop involved gathering together a particular community of software developers and researchers from mainly North America and Europe. This required an even-split of representation from the 2 continents, which is impossible to fund via the standard CECAM budget. In this case, we were able to pool extra money from the NFDI consortium FAIRmat, and also other local resources. However, this is not sustainable for a topic that should require growth in size and breadth.

2. Collborative Projects

- Indeed, one of the main goals (and also outcomes) of this workshop was to establish tangible collaborations between software projects. This was discussed, and the main options for funding appear to be either ERC joint schemes (for Euro-Euro collaborations), and NSF-DFG joint grants (for Euro-American collaborations).

Highlight of discussions -- Software is hard to fund, especially maintaining existing software

5 Will these developments bring societal benefits?

Research data infrastructure has emerged as one of the most important general topics in modern science. With data as an essential scientific commodity, continued progress relies on robust approaches for storing and sharing data. AI-ready data, e.g., has already demonstrated a capibility of paradigm shifts within individual communities and remarkable scientific breakthroughs. Within the molecular dynamics community, there is a plethora of possible applications that may be postively affected downstream due to FAIR-ification of data within the simulation community. Additionally, the climate crisis necessitates that we carefully assess the scientific communities impact on the environment. In this case, the repetative nature in which our community performs simulations is no longer acceptable. FAIR-data infrastructure has the potential to dramatically reduce our net footprint (or maximize the potential impact of each simulation run) by not only preventing duplication of simulations but also reducing mistakes and disincentivizing sloppy or incorrect simulations through the proper documentation of metadata.

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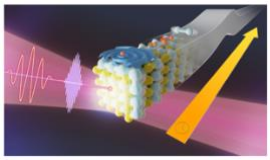

Atto2Nano: modeling ultrafast dynamics across time-scales in condensed matter

Location: CECAM-HQ-EPFL, Lausanne, Switzerland
Webpage : https://www.cecam.org/workshop-details/1193
Dates: Sep 26, 2023 - Sep 29, 2023

1 State of the art

The wide range of emergent phenomena and quasiparticles arising from excitation, correlation, and coherence of electrons, spin, photons, and nuclei provides a wealth of largely unexplored possibilities to achieve properties on demand in advanced materials. Achieving control of these phenomena constitutes the key to the formulation of novel technology concepts based on quantum materials. However, this requires a detailed understanding of light-matter coupling in many-body systems out of equilibrium via predictive ab-initio methods and semi-empirical approaches suitable to simulate time-resolved ultrafast dynamics.
Modelling non-equilibrium dynamics in solids involves capturing a wide and diverse landscape of excitations and fundamental interaction mechanisms spanning different time and length scales, as well as different levels of complexity. In recent years, a significant progress was attained in experimental, theoretical, and computational capabilities to explore ultrafast processes ranging from attoseconds to nanoseconds thus enabling new routes and perspectives for the reliable prediction of excited-state dynamics in advanced materials.
In spite of the remarkable progress in the theoretical description of ultrafast processes – such as, e.g., coherent phonon excitations, driven topological insulators, two dimensional semiconductors and magnetic systems –, the rich interplay of several coupling mechanisms and many-body interactions across multiple length and time scales often hinders a thorough theoretical understanding of non-equilibrium phenomena in advanced materials. These considerations outline the urgency of establishing novel concepts to bridge spatio-temporal scales in the theory of ultrafast phenomena and their implementation in efficient computational methods.

2 Major outcomes

This workshop brought together researchers with complementary expertise in the field of experimental and theoretical ultrafast science with the goal of stimulating discussion and exchange on bridging time-scales in both ab-initio and semi-empirical approaches for non-equilibrium phenomena, focusing on time-scales ranging from attoseconds to nanoseconds. While the primary focus of the workshop was on theoretical and numerical modelling of ultrafast dynamics, our event further attracted participation of emerging and leading experimentalists from the area of time-resolved spectroscopy and microscopy. Overall, this event contributed to generate an open and diverse environment that stimulated discussions and collaborations on new theoretical and computational horizons for the description of non-equilibrium dynamics and time-resolved excited-state phenomena.
We discuss in the following a selection of the open challenges, unsolved problems, and available opportunities in the field of ultrafast science that have emergence throughout discussion and presentations featured during this CECAM workshop.
- Quasiparticle formation at attoseconds timescales. The dynamics of solids on attosecond timescales features coherence, complex many-body interactions, and unexplored emergent phenomena. These timescales remains among the most challenging to tackle from both theory and experiments. One challenge consists in revealing the emergence of quasiparticle excitations (e.g., excitons, plasmons, polaritons), but also in the extablishment
- **Decoherence**. Understanding decoherence is an issue of utmost importance for enhancing the coherence time of entangled states, with direct implications for quantum computing, or for

the detection of Floquet states. Novel ab-initio theories and computational approaches for decoherence have been widely discussed at the workshop. Yet, the consensus emergenced that further efforts are required to better understand, model, and predict possible decoherence mechanisms in quantum materials.
- **Floquet theory.** The formation of Floquet states -- replicas of the electron bands in a periodic potential -- is emerging as a novel unifying concept in ultrafast science. Discussions and presentations held at this workshop have revealed a diverse spectrum of phenomena that can be understood within the formalisms of Floquet theory including, e.g., cavity embedding, light-driven solids, or coupling to lattice vibrations. Overall, the concept of Floquet band structure is emerging as a powerful paradigm for engineering the band structure of solids.
In addition to these emerging topics, the workshop featured several presentations on the recent advances in the theoretical, compuational, and experimental investigation for a broad spectruym of ultrafast phenomena, including nonlinear effects (e.g., high-harmonic generations), exciton dynamics, exciton-phonon coupling, lattice dynamics, and quantum nuclear effects.

3 Community needs

Computational studies of ultrafast phenomena require to explicitly account for different interaction mechanisms, quasiparticle formation, and coherence. These phenomena typically entail a high numerical cost as well as high memory consumption. Future development in this fields depend on the capability to exploit at best the next generation of supercomputing infrastructures, as well on the formulation on novel paradigms for highly-paraller simulations (e.g., by augmenting the capabilities of exisitng codes via machine learning).
Networking is and remains a fundamental pillar of scientific progress in the field of ultrafast science. In particular, advancements in this field strongly rely on the establishment of synergies between experimental and theoretical researchers -- to validate theories or explain findings. The organization of dedicated workshops can thus be extremely beneficial to consolidate and extende these synergies, and to foster new collaborations. A series of)CECAM workshops on the theoretical modelling of ultrafast phenomena could indeed be extremely beneficial for this scope, providing a gravitational center for the emerging scientific community with common interests in this area.

4 Funding

Typical funding channels for fostering research in the topical area of this workshop include European programs (e.g., Horizon 2020) and national programs (e.g., national research foundations). Other funding venues (private foundations, or programs for industrial cooperation) are also available in few EU countries.
During the meeting several discussions took place for initiating or kick-starting joint research endeavours. The joint attendance of experimentalists and theoreticians proved very useful to establish a common language and background, and favoured the identifications of open problems and challenges. This provides a fertile ground for future collaborative endeavours.
One such collaborative effort is exemplified by the recently founded doctoral training network of the Marie Skłodowska-Curie Actions focusing on "Time-resolved simulations of ultrafast phenomena in quantum materials" (TIMES), involving a selection of participants and organizers to the workshop.

5 Will these developments bring societal benefits?

The subject of this workshop concerned fundamental aspects of solid state physics and, in particular, the theoretical modeling of quantum materials, novel physical phenomena, and their ultrafast dynamics in condensed matter and molecular systems. This is an area of fundamental research in solid state physics that has not yet reached maturity for integration into marketable technologies (technology readiness level 1). It is therefore mostly focused on fundamental

research. Yet, advancing the fundamental understanding of ultrafast phenomena holds the promise of unlocking new directions and opportunities for controlling the quantum properties of materials, extending the toolbox at our disposal for engineering materials functions starting from their fundamental building blocks. Owing to the versatility of these concepts, ultrafast science has been envisioned as a likely route to impact a broad span of applications and technologies, including energy storage, quantum computing, information storage, and photocatalysis.

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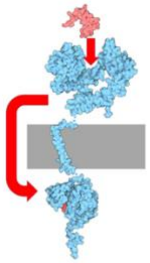

Making the invisible protein life visible using integrative biophysical approaches: Structural and dynamic characterization of hidden protein states and allosteric regulatory landscapes

Location: CECAM-Lugano, Aula Magna, USI West Campus, Lugano, Switzerland
Webpage : https://www.cecam.org/workshop-details/1201
Dates: Oct 4, 2023 - Oct 6, 2023

1 State of the art

Allosteric regulation is a fundamental mechanism employed by cells to control critical processes such as signal transduction, catalysis, and gene regulation [1-3]. While studies of allosteric regulation have often focused on thermodynamic aspects, there has been an increasing realization of the role of conformational dynamics [4-5]. Recent advances in NMR [6], cryo electron microscopy [7-8] and biophysical techniques that enabled detailed investigations of large protein systems at atomic resolution have fueled the resurgence of computational and theoretical studies of allosteric regulation, leading to new conceptual outlooks of this long-standing biological phenomenon [9]. High-pressure NMR experiments can be used to detect of low-lying excited functional states, providing another tool to investigate the dynamic energy landscapes [10]. Simulation-based computational approaches allow substantive comparative studies of allosteric networks of regulation and are increasingly being combined with NMR and cryo-EM investigations [11-12]. The ability to measure accurate distances and kinetics with Single-molecule FRET (smFRET) has led to its emergence as an important tool for mapping biomolecular heterogeneities and for measuring structural dynamics over a wide range of timescales [13-15]. Despite the established view that complex protein systems and regulatory complexes often function as dynamic and versatile allosteric machines, the characterization of hidden and rare protein functional states, allosteric conformational transformations and allosteric pathways is still surprisingly limited, calling for the integration of novel structural, biophysical and computational approaches to address these challenges.

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*[14] E. Lerner, A. Barth, J. Hendrix, B. Ambrose, V. Birkedal, S. Blanchard, R. Börner, H. Sung Chung, T. Cordes, T. Craggs, A. Deniz, J. Diao, J. Fei, R. Gonzalez, I. Gopich, T. Ha, C. Hanke, G. Haran, N. Hatzakis, S. Hohng, S. Hong, T. Hugel, A. Ingargiola, C. Joo, A. Kapanidis, H. Kim, T. Laurence, N. Lee, T. Lee, E. Lemke, E. Margeat, J. Michaelis, X. Michalet, S. Myong, D. Nettels, T. Peulen, E. Ploetz, Y. Razvag, N. Robb, B. Schuler, H. Soleimaninejad, C. Tang, R. Vafabakhsh, D. Lamb, C. Seidel, S. Weiss, eLife, **10**, (2021)*
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2 Major outcomes

The major scientific points discussed in the meeting were:

a) Theoretical and computational models of allosteric regulation on different time scales: accelerated MD simulations, Markov State models, non-equilibrium simulation methods.
b) Experiment-informed modeling of allosteric biomolecular assemblies, network models, dynamic network flows, NMR-based simulation approaches, systems-biology simulations of regulation in the cellular environment.
c) New methods and developments in the non-equilibrium simulation methods for modeling of allosteric ensembles and pathways
d) Latest developments in structural characterization of allosteric molecular events and hidden functional states important for allosteric function using cryo-EM, NMR, smFRET spectroscopy and integrative computational biophysics approaches.
e) d) Computer simulation methods and experimental NMR, smFRET tools for unveiling the invisible aspects of protein 'life' including the determination of hidden protein states.
f) Integration of smFRET tools with advanced sampling and non-equilibrium simulation methods for studies of slow conformational dynamics and allosteric transformations in protein systems
g) Open questions and challenges in the field, particularly opportunities for integration of NMR, smFRET and advanced computational sampling approaches.

While the main objectives of the workshop were:

1. Focus on the latest developments in structural characterization of allosteric molecular events and hidden functional states important for allosteric function using cryo-EM, NMR, smFRET spectroscopy and integrative computational biophysics approaches.
2. Discuss progress and identify integrative tools for unveiling the invisible aspects of protein 'life' including the determination of hidden protein states.
3. Analyze and discuss new methods and developments in the non-equilibrium simulation methods for modeling of allosteric ensembles and pathways.
4. Focus on approaches for integration of smFRET tools with advanced sampling and non-equilibrium simulation methods for studies of slow conformational dynamics and allosteric transformations in protein systems.
5. Develop a perspective on the progress and role of emerging technologies in quantifying dynamics and kinetics of allosteric events and detecting hidden rare functional states (high-pressure NMR, cryo-EM. smFRET, experiment-guided biophysical modeling, AI and machine learning as enabling tools for integration of the theory and experiment).
6. Discuss open issues and challenges in the field, particularly opportunities for integration of NMR, smFRET and advanced computational sampling approaches
7. Bring together cryo-EM. NMR, smFRET and computational communities to develop strategic views on allosteric phenomena in molecular biology.
8. Discuss Open Science, Shared Infrastructure and Data Exchange between cryo-EM, NMR, smFRET and computational communities to develop strategic views on allosteric phenomena in molecular biology.
9. Open exchange and discussion about new developments and current status in the field.
10. Provide opportunities and engage students and early-career researchers to discuss their projects in a poster session and contributed talks.
11. Address gender inequality in science by promoting participation of women and minorities.
12. Promote networking between students, early-career and more experienced researchers.

3 Community needs

Computational Infrastructure The community expressed the need for improved computational infrastructure, including the development and optimization of existing codes (such as GROMACS) for large-scale protein system investigations. The use of High-Performance Computing (HPC) resources was deemed essential for conducting substantive comparative studies of allosteric networks of regulation.
Networking There was a consensus on the need for increased outreach to other communities, particularly experimentalists. This would foster a more integrative approach, combining experimental investigations with computational studies for a comprehensive understanding of allosteric regulation.
Event Organization The participants agreed on the value of organizing a series of CECAM workshops on this topic. The rationale behind this was the complexity and versatility of protein systems and regulatory complexes, which necessitate continuous discussion and knowledge exchange. These workshops would provide a platform for presenting novel findings, discussing challenges, and brainstorming solutions in the field of allosteric regulation.
In conclusion, the workshop highlighted the importance of integrating structural, biophysical, and computational approaches in the study of allosteric regulation. It also underscored the need for improved computational infrastructure, increased networking, and regular event organization to facilitate progress in this field.

4 Funding

During the workshop, we had extensive discussions about the need for additional funding channels to support research in this critically important field. The importance of involving both U.S. and European funding agencies in these discussions was emphasized, as their input and support could significantly advance the field.
We identified several key stakeholders and program chairs from various funding agencies who should be involved in these discussions. These include representatives from Horizon 2020, a flagship initiative by the European Union that funds research and innovation with a focus on societal challenges such as health, clean energy, and digital technologies.
From the U.S., we highlighted the need to involve representatives from the National Science Foundation (NSF), which supports fundamental research across all fields of science and engineering, and the National Institutes of Health (NIH), which is the primary agency of the U.S. government responsible for biomedical and public health research.
We also discussed the importance of involving the Swiss National Science Foundation, given its role in promoting scientific research in Switzerland. Their involvement would be particularly relevant for research collaborations involving CECAM HQ and other Swiss institutions.
The consensus from the discussions was that these agencies might not only provide valuable insights into the direction of research in this field, but could also potentially provide additional funds to organize future meetings. This would facilitate ongoing dialogue and collaboration among researchers, thereby accelerating progress in this field. The potential for such funding opportunities underscores the importance of engaging with these agencies and involving them in our discussions.

5 Will these developments bring societal benefits?

The research topic of the workshop, which focuses on the structural and dynamic characterization of hidden protein states and allosteric regulatory landscapes, has significant potential societal benefits:
Economic Benefits The methods developed through this research can be adopted by various industries, particularly the pharmaceutical and biotechnology sectors. These methods can expedite the process of drug discovery and development, leading to cost savings. Moreover,

they can stimulate innovation, leading to the creation of new products and services, which can contribute to economic growth.
Societal Benefits The research can contribute to sustainability in several ways. For instance, understanding protein dynamics can aid in the development of more efficient enzymes for industrial processes, reducing the environmental impact. Additionally, the knowledge gained can be used in the design of novel bio-based materials, contributing to the transition towards a circular economy.
Health Benefits The most direct impact of this research is likely to be in the field of health. Understanding allosteric regulation and protein dynamics can lead to the design of novel drugs that target specific protein states, potentially leading to more effective and safer treatments for various diseases.
Funding Opportunities Given the potential benefits, there are numerous funding opportunities for this research. For instance, the European Union's Horizon Europe program has several calls related to health, biotechnology, and sustainability that could be relevant. Similarly, the National Institutes of Health (NIH) in the U.S. funds research in these areas. Industry partnerships can also provide funding, particularly from pharmaceutical and biotechnology companies interested in drug discovery and development.

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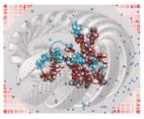

The Structural Genome: Merging Physics, Biology and Computation

Location: Scuola Internazionale Superiore di Studi Avanzati (SISSA, Trieste, Italy)
Webpage : https://www.cecam.org/workshop-details/1149
Dates: Oct 11, 2023 - Oct 13, 2023

1 State of the art

The information expressed by a single DNA filament combines elements from the polynucleotide sequence with the three-dimensional folding of the sequence in the space of the cell. The latter, in particular, influences how genomes respond to external stimuli and attacks which may cause trouble to the healthy behavior of the cell.
The structure/function relationship of genomes is the focus of an intense multi-disciplinary effort, where experimental teams (super-resolution microscopy, chromosome conformation capture, in-vivo fluorescence imaging, ...) work side-by-side with theoretical ones (physical/mathematical models for the genomes, statistical analysis of gene expression profiles, bioinformatics analysis of DNA sequences, ...), with the mutual greatest benefit.
In this meeting, we have brought together an interdisciplinary audience including both experimentalists and experts of theory, computer simulations and data analysis. It has been an informal and interactive session favoring discussion and vision development for the future of this field and its interaction with different areas of biology. The duration of the meeting was 2.5 days, during which recognized PI's and young researchers (PhD and post-docs) have presented the state-of-the-art of the field.

Key References

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2 Major outcomes

We have summarized the major outcomes of the meeting in the following list:
1) It is now clear that protein condensates are one of the fundamental mechanisms regulating chromatin organization and gene expression. On the other hand, how condensates form in space and time and how they couple to chromatin dynamics is not known in detail. The workshop has presented numerous modeling and experimental attempts along this research line. In particular, during some talks it has emerged quite clearly that condensates form because the corresponding proteins interact with each other through the mediation of the chromatin fiber. In our opinion, this is an interesting mechanism whose physical consequences need to be explored more carefully in the future.
2) Chromatin itself is a polymer and, in general, a very long polymer tightly confined within the narrow environment of the nucleus. Nuclear confinement enhances the topological barriers which exist between distant chromatin fibers, this naturally affects chromatin dynamics however up to which extent remains to be characterized and understood. This was one of the emerging points of the workshop, which needs to be tackled in the future.
3) Another fundamental issue concerns the interplay between chromatin packing, chromatin dynamics and the role of activity inside the nucleus of the cell. This is not only a topic of biological interest, but it has interesting theoretical implications: by looking at chromatin as an "active polymer", one deals with a system where the usual stat mech rules (equilibrium, ergodicity, detailed balance, etc...) are violated and a new framework becomes necessary. In one of the talks of the workshop, in particular, it has emerged clearly that the breaking of detailed balanced in a solution of active chromatin fibers induces unexpected hydrodynamic-like interactions. This is a mechanism which certainly deserves more focused investigation in the near future.
Overall, we believe that these are the major scientific points which have emerged during this recent event.

3 Community needs

The workshop has witnessed the participation of experimental biologists, of theoretical physicists and chemists, as well as of bioinformaticians. During the days of the workshop, this heterogeneonous commutinity has been involved in many stimulating discussions during which it has emerged quite clearly that advanced computing tools (in the form of large-scale simulations of polymer-like chromatin models, images analysis, machine-learning and other sophisticate AI methods) play - and will play more and more in the future - a fundamental role in the decryption of the relationship between structure and function of the genome.
In the past, CECAM has already sponsored analogous workshops on these topics, always with great success and participation. The "series" has been interrupted by the covid-19 epidemics and, at least to our knowledge, this is the first event sponsored by CECAM after that: given the importance of the topics and their relevance for, e.g., public health (see below), we encourage CECAM to consider the sponsorization of events on these, or related, topics in the years to come.

4 Funding

The meeting has been funded entirely by the CECAM-IT-SISSA-SNS Node, based in Trieste (Italy), without additional fees for the participants. In total, the cost of the meeting has been in the amount of ~10,000 euros: the money has been mainly used to cover the accommodation and meals for the invited speakers (16 people), as well as to insure some coverage for the contributing speakers and the rest of the participants. We have not explicitly sought additional funding; for the future, however, it would be desirable to look for it (in the form of small funding schemes) in order to cover the expenses of the youngest participants.

5 Will these developments bring societal benefits?

The main research topic of this workshop has a great potential for health benefits. Chromosome organization is a highly dynamic environment: chromosomes replicate and divide, while assisting vital processes like gene expression and regulation. Ordinarily, these processes are at the basis of the normal functioning of each individual, from unicellular to multicellular organisms like plants and animals. On the other hand, from time to time, chromosomes may undergo mulfunctioning (like when mutations happen) which may lead to pathological conditions such as, for instance, cancer in mammals. Understanding when mutations and other irregular behavior is about to happen and, eventually, prevent them is a challenge for the future, which requires a quantitative understanding of the cellular processes. Workshops like the one here aim at that: through the collaboration of biologists, biochemists and biophysicists it should become finally possible to reach a mechanistic understanding of cell behavior and of the occurrence of pathological conditions.

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Quantum2 on machine learning enhanced sampling

Location: CECAM-HQ-EPFL, Lausanne, Switzerland & online (hybrid format)
Webpage : https://www.cecam.org/workshop-details/1255
Dates: Nov 29, 2023 - Dec 1, 2023

1 State of the art

The workshop focuses on the intersection of enhanced sampling methods (ES) and machine learning potentials (MLPs) in classical molecular dynamics (MD) simulations, with the inclusion of nuclear quantum effects (NQEs). ES enables efficient exploration of configuration space, while MLPs promise ab initio accuracy at the price of a force field, making it possible to include solvent effects in chemical reactions. Despite their individual strengths, challenges arise when NQEs become crucial, such as in hydrogen-bonded systems and biological processes like DNA interactions. In this workshop, we wanted to address key questions at this interface, such as exploring ways to tailor ES algorithms for constructing effective MLP training sets. The communities of the three domains being quite distinct, the main aim of this workshop

was to unite them in order to build bridges between NQEs and ES, mainly by the use of ML methods. The list of participants included leading experts in NQEs, ML and ES as well as young researchers who interacted through oral presentations, a poster session, and discussion sessions in small groups. One of the major remarks that was made during this workshop was that most of the participants were familiar with at least two of the domains but not the third one: for instance, some people used NQE methods as well as ML ones but did not know about ES. Therefore, the workshop opened up new research directions for them. The insights and outcomes presented here serve as a valuable resource for researchers interested in pushing the boundaries of classical MD simulations at the intersection of these diverse yet interconnected fields.

2 Major outcomes

We held four one-hour discussion sessions, each focused on specific topics, with participants submitting questions beforehand. To encourage engagement, participants were randomly assigned to three groups, collectively addressing submitted questions during these sessions. Here's a summary of each discussion:

Session 1: Nuclear Quantum Effects (NQEs)

Explored challenges in NQEs, covering computational costs, efficiency, and strategies for scalability, particularly in large systems like biomolecules. Discussed collaborative strategies such as unified Machine Learning models, standardized data sources, tutorial resources, databases, and emphasizing accuracy and reproducibility. Highlighted the need for validating theories with challenging predictions, focusing on small systems for benchmarking. The discussion also emphasized the need to establish a hierarchy for NQE methods and use on-the-fly calculation with Path Integral in order to avoid holes in quantum dynamics simulations.

Session 2: Machine Learning (ML)

Discussed challenges in ML interatomic potentials, focusing on benchmark data, criteria for effective ML methods, and model consistency verification. Highlighted the importance of standardized benchmark data, practical ML methods with efficient performance, and ensuring model consistency through supplementary thermodynamic quantities.

Session 3: Enhanced Sampling (ES)

Explored techniques for accelerating simulations through ES while preserving accuracy. Topics included integrating NQEs in ES, balancing efficiency and accuracy, optimizing collective variables, and predicting thermodynamics and kinetics. Noted the increasing use of ML in ES, suggesting the implementation of complex descriptors in freely available software like plumed and their use as input for ML models, such as autoencoders.

Session 4: Joint Session

Brought all groups together to discuss ideas and conclusions from previous sessions, aiming to identify collaboration opportunities and relevant questions in each field. A significant outcome of the workshop was the rich content that emerged from these discussions. Participants worked together to distill key insights, which were then summarized and presented in a series of slides prepared by each group.

Additionally, the workshop innovatively addressed diversity and inclusion in science through a dedicated hour. Specific questions were posed to the audience, who responded via real-time polling on an online platform. This was followed by a comprehensive discussion exploring the importance of diversity and inclusion in science, alongside best practices for fostering it in scientific environments. An analysis of poll responses indicated overwhelming participant acknowledgment of the significance of diversity and inclusion in advancing scientific progress. Participants highlighted how diverse perspectives contribute to creativity and problem-solving. In response to open-ended questions, practical strategies for promoting diversity were shared, including adopting English as a universal scientific language, aiding foreigners in visa processes, and actively seeking diverse talent within research labs.

3 Community needs

The community's requirements in the field of Machine Learning, Nuclear Quantum Effects (NQEs), and enhanced sampling span diverse aspects, including computational infrastructure, networking, and event organization. Regarding computational infrastructure, there is a need to identify and rectify gaps in existing codes, particularly those dedicated to simulating NQEs. Encouraging collaborative efforts to enhance and develop codes is strongly recommended. Additionally, facilitating access to High-Performance Computing for resource-intensive simulations is imperative as is the establishment of guidelines for optimizing code performance. Addressing the computational infrastructure, networking, and event organization needs necessitates a strategic and collaborative approach. Proposing a series of CECAM workshops emerges as a central strategy to foster collaboration, skill development, and the dissemination of knowledge within the community. This approach ensures the depth and relevance of discussions, especially with the incorporation of hands-on sessions.

4 Funding

While the prospect of collaborative research proposals was not explicitly addressed, a noteworthy suggestion emerged regarding leveraging community competitions as a catalyst for advancing the integration of ML techniques and ES methods to account for NQEs in molecular dynamics. These competitions could adopt a format similar to those found on platforms such as Kaggle.com or the Critical Assessment of Structure Prediction (CASP), providing a structured and engaging way to drive progress in this dynamic field.

5 Will these developments bring societal benefits?

The use of machine learning potentials and enhanced sampling techniques in the context of NQEs have a direct ecological and financial impact. Indeed, using them reduces by at least one order of magnitude the computational burden of electronic structure calculations. This efficiency gain not only accelerates scientific research but also aligns with a more sustainable approach by curbing the ecological footprint associated with energy-intensive computations. The adoption of more efficient techniques aligns with the broader goal of promoting environmentally conscious practices in scientific research. From a financial standpoint, the decreased computational workload translates into cost savings, making these simulations more accessible to a wider range of researchers and institutions. On the other hand, the enhanced accuracy afforded by including NQEs in faster simulations can significantly streamline industrial processes, e.g., in the pharmaceutical industry, potentially accelerating breakthroughs in drug discovery and beyond.

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Chemical Concepts from Theory and Computation

Location: Institut des Sciences Analytiques, Villeurbanne, France
Webpage : https://www.cecam.org/workshop-details/1219
Dates: Dec 11, 2023 - Dec 13, 2023

1 State of the art

Chemical "*in silico*" simulations are nowadays close to replace chemical experiments. Yet as the calculations become both more sophisticated and accurate, the gap between the simulation outputs and their chemical interpretation[1] grows larger and larger.
Density functional theory (DFT) is accepted as the most prevalent computational method developed in past decades. However, most people are unfamiliar that DFT also provides a conceptual framework. Conceptual DFT[8,9,10] (CDFT) provides robust mathematical and physical grounds for conventional chemical concepts like electronegativity[11], hardness[12], electrophilicity[13], and many other[14–17], but is still somewhat **controversial**. Similarly, Quantum Chemical Topology (QCT) descriptors are gaining popularity in the theory of chemical bonding. Sharing the same basic ingredient (i.e. the electron density and its derivatives), these approaches divide the real-space into chemically meaningful regions such as atoms (QTAIM[18]), cores, bonds or lone-pairs (ELF[19]) or highlight non-covalent interactions (Non Covalent Index or NCI[20]).

The purpose of this symposium was to foster discussions between experts from the DFT, MOT and VBT and QTAIM communities on stability, bonding, reactivity, non linear optics, molecular electronics, among others. Another field, been widely represented, is the application of Artificial intelligence in chemistry with a special session dedicated to this topic.

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2 Major outcomes

The program has been intense. Lots of points have been discussed during the workshop. The main concern of interpretative theories are the notions of molecular stability, reactivity, aromaticity and antiaromaticity. It appears after the workshop that these concepts are still quite complex to describe from ab initio calculations and rather elusive. These properties are not quantum observable and therefore no quantum operators can be defined. Three other topics have been widely discussed:
The evolution of the chemical behavior of molecules under electric fields and magnetic fields. If the calculation of the interaction energy and electron density polarization are not the issue, the understanding and rationalization of the reactivity and selectivity due to the fields is still difficult to grasp. Preliminary results suggest no selectivity changes under magnetic fields. For electric fields situation is much more mitigated. The characterization of chemical bond, chemical reactivity and chemical selectivity at excited state is a rising topic. A session has been dedicated to this domain. Several ways to compute quantum descriptors such as ELF and the electron density polarization for low lying excited state have been proposed. However, as a new topic the interpretation of such quantities are still to be understood. The multi determinantal nature of excited states wave function makes add a layer of issues in the rationalization of the chemical selectivity. Finally the last topic discussed is the introduction of Artificial intelligence in the field. The gain in computational resource is outstanding for ab initio computation. As such the use of Neural Network of the ANAKIN-ME family shows a huge potential for large molecules. Besides, quantitative relations between structure and properties become much more precise. However, even though the prediction become more and more accurate the interpretation becomes more and more elusive due to the huge number of descriptors in play.

3 Community needs

As already mentioned, the aim of the workshop was to gather the main players in the interpretative theories of reactivity and selectivity. These theories need the development of post ab initio calculation codes. More precisely codes using the electron density, eigenvalues, eigenfunction to extract chemical concepts such as electronegativity, electrophilicity, nucleophilicity to name a few. So the need for HPC is very limited. Contrarily to electronic structure computation or ab initio calculation, the community is not that mature. Each and every group develop its own code for calculating the electron response it is interested in. Very few codes are versatile (Multiwfn and ChemTools), other are more specialized such as NCIPlot and TopChem2. some codes not even downloadable. Most of them are not user friendly. As the main aim is to provide tools for fill the gap between theoreticians and experimentalist, this is an important draw back that needs to be tackled.
On another topic, the Workshop has been an opportunity to network and build new collaboration between participants. Indeed, several participants had some common research objects and different ways to approach the subject. Excited states, ML applied to chemical reactivity are example of topics will lead to new collaborations. It appears that the chemical concepts are still alive and kicking. It has been decided to organized a fourth issue of the CCTC in Hawai in 2025.

4 Funding

The community lacks specific funding calls. This is true worldwide. This situation is based on several reasons. First, as fundamental science, it is difficult to directly link any breakthrough to a way to tackle a societal issue. Second, quantitative theories with solid numbers are generally preferred over qualitative ones. So generally, chemists interested in chemical concepts tried to coat the core of their research within a wider project. The conceptual part being a side-project. However, CCTC#3 have provided the opportunity for researcher working on the same concepts to joint forces for speeding up both their development but also the coding. For instance, it has been plain to see that an exact formulation and exact calculation of linear response function is mandatory for further application. This formulation will be developed and implemented in ChemTools during 2024 Q1 by two participant from different labs (France and Canada). (Static Linear Response Function is how a 6 dimensions function that enable to compute the variation of the electron density in one point when the external potential is modified in another point).

5 Will these developments bring societal benefits?

Chemical Concepts from Theory and Computation are generally far from direct application in societal issues. The concepts aim to provide tools to rationalize experimental results and may be on the long run guide new research. The ultimate goal being prediction that seems to be reachable through artificial intelligence. However, if prediction can be achieved, the range of potential applications is quite large. Thus, direct application can be held in chemical synthesis, with increased rates and yields. For instance the application of External Oriented Electric Fields, discussed in three presentation show interesting preliminary results in stereoselectivity. Other direct applications of these development lies in the design of specific chemicals or materials with targeted properties, be it in the pharmaceutical industry with new approaches in drug design or in the development of smart materials. This is especially true with the help of Machine Learning. Two presentations have been dedicated to material design and Machine Learning. The development of excited state descriptors provide a better understanding of the behavior of chemical in these states. The obvious application being the design of new molecules fitted to enhanced the photon harvesting leading to more efficient solar cells.

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MIXED-GEN WEBINARS

Mixed-Gen was first imagined as a venue for PhD students and young researchers to share their work, get expert feedback and have an opportunity to strengthen their scientific relations when in person meetings were impossible due to CoVid. Very positive feedback from the community testifies to the value of this idea.

Each session of the series has two parts. In the first, broadcasted on Zoom, an experienced scientist presents an advanced topic in different areas of simulation and modelling, followed by young members of the community describing their work in the same area. In the second part, a virtual poster session takes place on GatherTown, where more PhD students and researchers in their first post-doc present pertinent projects to the session's speaker as well as other expert guests and participants.

Mixed-Gen Season 3 – Session 3: Soft matter and machine learning

January 26, 2023, 15:00 – 19:00 CET

Soft matter and machine learning

Laura Filion, Utrecht University

Developments in machine learning (ML) have opened the door to fully new methods for studying phase transitions due to their ability to extremely efficiently identify complex patterns in systems of many particles. Applications of machine learning techniques vary from the use of developing new ML-based order parameters for complex crystal structures, to locating phase transitions, to speeding up simulations. The rapid emergence of multiple applications of machine learning to statistical mechanics and materials science demonstrates that these techniques are becoming an important tool for studying soft matter systems. In this talk, I will briefly present an overview of the work my group is doing on using machine learning to study soft matter systems, with a focus on new strategies to connect the dynamics and structure in glassy fluids.

Learning mappings between equilibrium states of liquid systems using normalizing flows

Alessandro Coretti, Sebastian Falkner, Phillip Geissler, Christoph Dellago, University of Vienna

In the framework of Deep Learning, generative models are getting increasing attention due to their ability of generating completely new samples starting from a set of given examples. The use of these tools in statistical mechanics is really tempting considering the difficulty of generating decorrelated samples from the Boltzmann distribution, notwithstanding the knowledge of its analytical expression. This path of thoughts has been followed in recent publications and physical configurations [1,2] as well as reactive trajectories [3] have been generated using a particular network architecture called normalizing flows, with very interesting results for biophysical and many-body systems.

The standard approach of these models consists in training a network to transform samples from an easy-to-sample distribution (e.g a Gaussian or a uniform distribution) to samples obtained from the correct Boltzmann probability. In particular, normalizing flows are built in such a way so that it is possible to reweight the network-generated density to obtain samples that are exactly distributed according to the Boltzmann distribution. Yet, the training process of such networks can be painful, in particular for disordered systems, where prior and target distributions are very different from each other.

In this view, this study [4] aims at exploring different choices for the prior distribution which are closer, from a physical point of view to the target one. This can lead on the one hand to an efficient exploration of the space of thermodynamics variables for a given model and, on the other, to the possibility of transforming between configurations obtained using different representations of the same physical system. Proof-of-principles calculations are presented for disordered systems of particles at different thermodynamics states and with different potential energy functions.

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Glass Transition in Polymer Melts using Data-driven Methods

Atreyee Banerjee, Hsiao-Ping Hsu, Kurt Kremer, Oleksandra Kukharekno, Max Planck Institute for Polymer Research

On cooling, the dynamical properties of many polymer melts slow down exponentially, leading to a glassy state without any drastic change in static structure. Understanding the nature of glass transition, as well as precise estimation of the glass transition temperature (Tg) for polymeric materials, remain open questions in both experimental and theoretical polymer sciences. We propose a data-driven approach, which utilises the high-resolution details accessible through the molecular dynamics simulation and considers the structural information of individual chains. It clearly identifies the glass transition temperature of polymer melts of semiflexible chains. By combining principal component analysis (PCA) and clustering (shown in the schematic), we identify glass transition temperature at the asymptotic limit even from relatively short-time trajectories, which just reach into the Rouse-like monomer displacement regime. We observe that fluctuations captured by the principal component analysis reflect the change in a chain's behaviour: from conformational rearrangement above to small vibrations below the glass transition temperature. We demonstrate the generality of the approach by using different dimensionality reduction and clustering approaches. The method can be applied to a wide range of systems with microscopic/atomistic information. More recently we applied this methodology to all-atom acrylic paint systems.

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Mixed-Gen Season 3 – Session 4: Simulation and modelling of electrochemical interfaces and capacitors

February 23, 2023, 15:00 – 19:00 CET

Electrode/electrolyte interfaces: from electronic response to interfacial structure, dynamics and thermodynamics using classical molecular dynamics simulations

Benjamin Rotenberg , Sorbonne University

Many key industrial processes, from electricity production, conversion, and storage to electrocatalysis or electrochemistry in general, rely on physical mechanisms occurring at the interface between a metallic electrode and an electrolyte solution, summarized by the concept of an electric double layer, with the accumulation/depletion of electrons on the metal side and of ions on the liquid side. While electrostatic interactions play an essential role in the structure, thermodynamics, dynamics, and reactivity of electrode-electrolyte interfaces, these properties also crucially depend on the nature of the ions and solvent, as well as that of the metal itself. Such interfaces pose many challenges for modeling because they are a place where quantum chemistry meets statistical physics. In this presentation I will review recent advances in the description and understanding of electrode-electrolyte interfaces with classical molecular simulations, and discuss in particular how to include some features of the electronic response in such simulations and their consequences on the interfacial properties.

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First-principles barrier simulations with implicit solvation model and electro-chemical potential

Mouyi Weng, Nicola Marzari, EPFL

Barrier simulation in real electrochemical condition is challenge due to the solvent environment and the electrochemical potential. Implicit solvation model [1] and Poisson-Boltzmann equations [2] can be implemented in density functional theory (DFT) for systems in solvent and electrolyte environment. Grand-canonical DFT can be used for a constant potential simulation [3]. With a latest grand-canonical self-consistent charge mixing method [4], DFT simulation with constant potential condition can be implemented. Here, combining with nudged elastic band (NEB) method [5], we tried to expand the constant potential DFT to barrier calculation. Formulas for forces and NEB in grand canonical functions are derived. Tests applications in real reactions (HER, ORR) are still in progress.

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Unified non-equilibrium simulation methodology for flow through nanoporous carbon membrane

Geoffrey Monet, Marie-Laure Bocquet, Lydéric Bocquet, ENS Paris

The emergence of new nanoporous materials, based *e.g.* on 2D materials, offers new avenues for water filtration and energy. There is accordingly a need to investigate the molecular mechanisms at the root of the advanced performances of these systems in terms of nanofluidic and ionic transport. In this work, we introduce a novel unified methodology for Non-Equilibrium classical Molecular Dynamic simulations (NEMD), allowing to apply likewise pressure, chemical potential and voltage drops across nanoporous membranes and quantifying the resulting observables characterizing confined liquid transport under such external stimuli. We apply the NEMD methodology to study a new type of synthetic Carbon NanoMembranes (CNM), which have recently shown outstanding performances for desalination, keeping high water permeability while maintaining full salt rejection. The high water permeance of CNM, as measured experimentally, is shown to originate in prominent entrance effects associated with negligible friction inside the nanopore. Beyond, our methodology allows to fully calculate the symmetric transport matrix and the cross-phenomena such as electro-osmosis, diffusio-osmosis, streaming currents, etc. In particular, we predict a large diffusio-osmotic current across the CNM pore under concentration gradient, despite the absence of surface charges. This suggests that CNMs are outstanding candidates as alternative, scalable membranes for osmotic energy harvesting.

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Mixed-Gen Season 3 – Session 5: Data science in biophysics for applications to drug discovery

March 23, 2023, 15:00 – 19:00 CET

Predicting protein-membrane interfaces using molecular simulations and ensemble machine learning

Zoe Cournia, Academy of Athens

Abnormal protein-membrane attachment is involved in deregulated cellular pathways and in disease. Therefore, the possibility to modulate protein-membrane interactions represents a new promising therapeutic strategy for membrane proteins that have been considered so far undruggable. In this talk, we explore the free energy landscape of membrane protein dimerization using parallel tempering metadynamics simulations in the well-tempered ensemble and coarse-grained force fields and reproduce the structure and energetics of the dimerization process of membrane proteins and proteins in an aqueous solution in reasonable accuracy and throughput [1] We propose that the use of enhanced sampling simulations with a refined coarse-grained force field and appropriately defined collective variables is a robust approach for studying the protein dimerization process, although one should be cautious of the energy minima ranking. Moreover, we study oncogenes, including the H1047R and E545K hotspot mutants of PI3Kα, [2] and KRAS-4B [3] using metadynamics to understand the basis of protein overactivation. We calculate their allosteric pathways and show residues important in delivering communication signals between functional domains of each protein.

Finally, we describe an ensemble machine learning methodology to predict protein-membrane interfaces of peripheral membrane proteins [5] and present a drug design pipeline for drugging protein-membrane interfaces using the DREAMM (Drugging pRotein mEmbrAne Machine learning Method) web-server https://dreamm.ni4os.eu. Taking into account these results, we investigate opportunities for allosteric drug design [6].

The research project was supported by the Hellenic Foundation of Research and Innovation (H.F.R.I) under the 1st call for H.F.R.I. Research Projects to support Faculty Members & Researchers and the Procurement of high-cost research equipment grant (Project Number: 1780).

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A nonequilibrium alchemical method for drug-receptor absolute binding free energy calculations: the role of restraints

Maurice Karrenbrock, Piero Procacci, Francesco Luigi Gervasio, University of Geneva

We test a method for calculating absolute binding free energies, that uses a combined Hamiltonian replica exchange and non-equilibrium alchemical approach, on 11 ligands of the bromodomain protein BRD4. The study demonstrates the benefits of using an improved sampling technique prior to alchemical transformations to obtain accurate estimates of binding free energies, even when starting from sub-optimal initial binding poses. The effect of different restraint mechanisms on the results is also investigated and a new 'Loose-Tight' restraint algorithm is introduced.

Overall, the method provides a good balance between ease of use, automation, speed and accuracy for the calculation of absolute ligand binding free energies, and the scripts provided allow easy integration into pre-existing computational drug discovery pipelines.[1]

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Unraveling the ribosome stalling mechanism induced by the human XBP1u arresting peptide

Francesco Di Palma, IIT

The eukaryotic ribosome stalling mechanism is a key biological process whose precise atomistic details are still elusive. In order to study in depth the 80S ribosome in a stalled state induced by the human XBP1u translational arrest peptide, we combined molecular dynamics and a “gentle” enhanced sampling simulation method. Multi-microseconds simulations (~15 μs) of the entire ribosome provided an atomistic picture of XBP1u-induced translational stalling mechanism in the presence of the nascent chain inside the exit tunnel; in this framework, we compared the effect of the *wt* XBP1u arresting peptide with the stalling induced by other 4 experimentally-selected significant mutants [1,2]. Together with the mechanistic details, by means of adiabatic bias molecular dynamics [3], we furthermore ranked the 5 variants in terms of detachment kinetics finding a nice correlation with their stalling strength [4]. The quantitative agreement between simulations and earlier experimental data supports our *in silico* outcomes, opening to future investigations in the field. Moreover, the amount of data collected paves the way for unprecedented pocket prediction opportunity on such a fundamental macromolecular target.

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Mixed-Gen Season 3 – Session 6: Simulation and modelling of non-equilibrium systems

April 27, 2023, 15:00 – 19:00 CET

Nonequilibrium molecular simulation: predicting results when theories don’t exist

Debra Bernhardt , The University of Queensland

The world around us in a nonequilibrium state, and although nonequilibrium statistical mechanics has seen some advances over the past decades, there are many problems that are still intractable. Problems become particularly difficult when a system is inhomogeneous and evolving in time, but even for nonequilibrium steady state systems predictive theories are not always available. An example is the determination of viscosities of complex non-Newtonian fluids undergoing shear flow. Nonequilibrium molecular dynamics simulations give us a way of predicting properties and understanding what happens at the molecular level in cases where theories currently do not exist – and in some cases this can lead to new

theories. They might also provide equilibrium properties when the equilibrium state is not readily accessible or numerical errors are too high at equilibrium. In this talk I will discuss how deterministic nonequilibrium molecular dynamics simulations can be used to model a range of systems and highlight some of the technical issues that need to be considered in carrying out this type of simulation.

Universal relation between entropy and kinetics

Benjamin Sorkin, Tel Aviv University

The theory of equilibrium thermodynamics is well established and key to the characterization of material properties. Out of equilibrium, for example in the presence of driving or activity, materials are routinely characterized by kinetic properties such as conductivities and diffusion coefficients, while thermodynamic quantities may be ill-defined or difficult to estimate. Relating thermodynamic quantities to kinetic ones is therefore a conceptual challenge with many practical benefits. Based on first principles, we derive a rigorous inequality relating the entropy of a material to the diffusion coefficient of its constituents. We do so by comparing two equivalent pictures — distinguishable particles undergoing diffusion, and indistinguishable particles that mix and approach steady state faster. The relation is universal and applicable to equilibrium as well as nonequilibrium systems. It can be used to obtain bounds for the diffusion coefficient (normal or anomalous) from the calculated thermodynamic entropy or, conversely, to estimate the entropy based on measured diffusion coefficients. We demonstrate the validity and usefulness of the relation through several examples.

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Active turbulence and topological defects in nematic liquid crystals

Pasquale Digregorio, University of Barcelona

Active materials are systems of many particles where single constituents consume energy from the environment and convert it into mechanical work. Active matter models are inspired by macroscopic living systems and biology, and their study is primarily aimed towards a theoretical understanding of collective phenomena like flocking, clustering and other types of self-organisation. Within a living cell, motor proteins like kinesin are responsible for the transport of intracellular components. The functioning of this active transport is well known and it has been employed to build synthetic assemblies of microtubules, which are stirred at the level of the single components and evolve out of thermal equilibrium. The presence of molecular motors drives chaotic flow at the large scale, which resembles inertial turbulence and is therefore called active turbulence. We use a model of nematic liquid crystals in the presence of a microscopic active stress to study this system. The onset of active chaotic flows leads to a sustained proliferation of topological defects that retain some unique properties compared with passive liquid crystals. We analyse the morphology and dynamics of these topological defects to deduce fundamental properties of active turbulence.

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Mixed-Gen Season 3 – Session 7: Computational methods in biophysics for applications to drug discovery

1 June 2023, 15:00-19:00 CEST

In Situ Dynamics Reveal Unseen Vulnerabilities of Viral Glycoproteins

Rommie Amaro , University of California, San Diego

Viral glycoproteins are important targets for vaccine and drug design. I will discuss our efforts to provide never-before-seen views of these amazing molecular machines, for both SARS-CoV-2 and influenza. For the latter, we investigated the dynamics of influenza glycoproteins in a crowded protein environment through mesoscale all-atom molecular dynamics simulations. Our simulations reveal and kinetically characterize three large-scale molecular motions of influenza glycoproteins, which expose epitopes that are otherwise hidden in static experimental structures. I will also discuss how we are using advanced simulation methods in structure-based immunogen design efforts. Our work highlights the advantages of exploring and characterizing *in situ* dynamics of glycosylated proteins in their native, crowded environments.

The role of heparin in spike SARS-CoV-2 infection: from a model for heparan sulfates to a starting structure for antivirals

Giulia Paiardi, Heidelberg University

Despite clinical success with anti-spike vaccines, the emergence of new SARS-CoV-2 variants highlights the necessity for a deeper understanding of the infection mechanisms and the development of broad-acting therapeutics that can reduce viral burden.
SARS-CoV-2 infection is driven by the interaction of the viral spike glycoprotein with the host cell angiotensin-converting enzyme 2 (ACE2) receptor and heparan sulfate (HS) proteoglycans, co-receptors that are indispensable for SARS-CoV-2 infection [1,2]. Experimental data indicate that the HS-analog heparin acts as an antiviral agent against SARS- CoV-2 by binding the viral spike glycoprotein [2]. We previously revealed that long basic grooves on the spike accommodate heparin which, in turn, exerts its antiviral effect by direct and allosteric mechanisms [3]. Based on these results, we are tackling two open mechanisms.

1. The role of HS as co-receptors for spike infection is not yet fully understood. To investigate this mechanism, we carried out over 10us of conventional MD followed by tauRAMD simulation to systems of the spike glycoprotein homotrimer bound to ACE2 in the presence of zero to three heparin chains. Our data indicate that N-glycans and heparin stabilize the protein-protein interaction while affecting the ACE2 dynamics. Direct crosstalk between heparin and ACE2 N-glycans is identified. These mechanisms contribute to the understanding of the spike SARS-COV-2 infection mechanism.
2. The anticoagulant effect of heparin hinders its application as an antiviral to early-stage COVID-19 patients. For this purpose, we aimed to design heparin derivatives with antiviral but without anticoagulant activity by combining computational studies with biochemical and cellular inhibition assays. Our results suggest that N-O-sulphated and O-sulphated heparin derivatives exhibit higher antiviral activity than heparin, due to greater hindrance of ACE2 binding to spike. These results support the therapeutic potential of these heparin analogs.

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Using molecular simulations towards RNA targeting with small molecule drugs

Mattia Bernetti, Istituto Italiano di Tecnologia (IIT)

A large fraction of the transcribed RNA from the human genome is not translated into proteins, and it is nowadays clear that non-coding RNA molecules can play many functional roles. As such, they can also be involved in pathological conditions, opening the way to possibilities for therapeutic strategies, including the design of small molecule drugs able to bind and modulate the activity of RNA molecules to achieve a therapeutic effect.[1] Computational methods such as molecular dynamics (MD) simulations and molecular docking have become established tools in modern drug discovery,[2] but they have historically been employed to target proteins. Extending these established procedures to RNA targets poses several challenges, including the high flexibility and complex structural dynamics that they typically display.[3] Indeed, RNAs are usually seen as ensembles of conformations, more than a single prevalent one. Thus, reconstructing reliable structural ensembles describing the conformational dynamics of RNA molecules is of great importance.

Within this context, I will first show a successful example of reconstructing the conformational ensemble of a biologically relevant RNA molecule, namely the GTPase-Associated Center RNA.[4] Specifically, herein the goal was achieved by using a combination of small-angle X-ray scattering (SAXS) experimental data and enhanced sampling MD simulations. Subsequently, I will discuss how this general framework can be leveraged of towards a drug discovery perspective. In particular, the reconstructed ensemble for an RNA target can be used to take into account the RNA flexibility, in an ensemble-docking spirit.[3] In practice, the molecular docking exercise is repeated on each conformation included in the ensemble of the RNA target. In this respect, I will show our advances towards a pharmaceutically relevant RNA molecules, namely the Metastasis Associated Lung Adenocarcinoma Transcript 1 (MALAT1) RNA. By identifying an ensemble of conformations of this RNA, potential binding sites, and the use of docking/virtual screening procedures, our ultimate aim is to identify promising binders able to modulate its activity.

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CECAM MARVEL CLASSICS IN MOLECULAR AND MATERIALS MODELLING

In this lecture series, we take a different look at fundamental developments of simulation and modelling. Milestone conceptual steps, methods and algorithms are presented by their originators. These technical lectures are followed by an interview in which the speakers recall for us the period, problems, people and circumstances that accompanied these developments, providing important and unusual insight in the birth and growth of tools that we now take for granted.

This lecture series is co-organized by CECAM and MARVEL (http://nccr-marvel.ch/) at EPFL and broadcasted in webinar format.

Time-dependent density functional theory: past, present and future

Thursday September 28 2023, 18:00 CEST

Time-dependent density functional theory: from basic theorems to spectra to ultrafast dynamics

Eberhard K. U. Gross, Hebrew University of Jerusalem

In this lecture, time-dependent density functional theory (TDDFT) will be presented as a versatile and affordable method to deal with the dynamics of electronic systems. Earlier applications of TDDFT focused on the response to weak probes, thus providing a reliable description of spectroscopic data. In recent years, real-time TDDFT simulations of strongly driven systems have become increasingly popular to predict the dynamical behavior far from thermal equilibrium. We shall visualize the laser-induced formation and breaking of chemical bonds in real time, and we shall highlight non-steady-state features of the electronic current through nano-scale junctions. With the goal of pushing magnetic storage processes towards ever faster time scales, an optically induced spin transfer (OISTR) from one magnetic sub-lattice to another will be presented. The OISTR effect was first predicted in 2016 by TDDFT calculations and two years later confirmed in several experiments. The OISTR effect marks the birth of “atto-magnetism”. To use this and other quantum effects in real-world devices, one has to face the fact that quantum systems tend to lose their “quantumness” on a rather fast time scale. This effect, known as “decoherence”, has prevented to date the construction of scalable quantum computers. As a particular challenge for the future, we shall address the ab-initio description of decoherence.

Eberhard Gross *received his PhD in Physics in 1980 at the University of Frankfurt, Germany. From Frankfurt he moved to the University of California, Santa Barbara, to join the group of Walter Kohn, first as a postdoc, then as a Heisenberg fellow. In 1990, he became a Fiebiger Professor at the University of Würzburg, Germany. From 2001 he had a Chair of Theoretical Physics at the Free University of Berlin, and from 2009 to 2019 he was Director at the Max Planck Institute of Microstructure Physics in Halle, Germany. Since 2017, he has been Professor of Chemistry at the Hebrew University of Jerusalem, Israel. He is known as the inventor of time-dependent density functional theory (TDDFT). Together with Erich Runge, he proved a set of theorems which form the mathematical foundation of TDDFT. He furthermore developed the ensemble DFT of excited states, and an ab-initio approach to phonon-driven superconductivity which allows the reliable prediction of critical temperatures. He also is a co-author of two widely used textbooks, one on DFT and one on many-particle theory. In recent years, he developed the exact factorization, a novel methodology describing all aspects of non-adiabatic chemical dynamics, in particular electronic decoherence and the molecular Berry phase. His work has been recognized with several prizes and awards, including the 2016 Bernie Alder CECAM prize, the 2016 Tsungming Tu prize of the Taiwanese Ministry of Science and Technology, the Schlumberger Award with medal, and the CMOA senior medal. He holds an ERC Advanced Grant, and he is a Fellow of the American Physical Society as well as a Mercator Fellow of the Deutsche Forschungsgemeinschaft. He is a member of the International Academy of Quantum Molecular Science.*

Time-dependent density functional theory: from non-equilibrium phenomena to quantum materials engineering

Angel Rubio, Max Planck Institute for the Structure and Dynamics of Matter

One of the principal challenges in computational physics is to formulate an accurate yet computationally viable theory that can address non-equilibrium light-driven phenomena in molecules and quantum materials. Additionally, there is a need to simulate spatially and temporally resolved spectroscopies, ultrafast events, and newly emerging states of matter. In pursuit of this goal, TDDFT has emerged as the cutting-edge ab initio theoretical framework, enabling reliable and precise simulations of light-induced alterations in the physical and chemical characteristics of intricate systems. In this context, I will also introduce the recently developed framework of Quantum Electrodynamics Density-Functional Formalism (QEDFT). This framework offers a first-principles approach to predict, characterize, and

manipulate the spontaneous emergence of ordered phases in strongly interacting light-matter hybrids, referred to as polaritons These phases manifest both as ground states, resulting in novel states of matter, as well as metastable states. Noteworthy examples include photon-mediated superconductivity, cavity fractional quantum Hall physics, and optically driven topological phenomena in low dimensions. This exploration brings to light a burgeoning field, which we term "Cavity Materials Engineering" or the science of strongly correlated electron-photon interactions. We will conclude with the great challenges ahead in this captivating field of research.

Angel Rubio *received his PhD in Physics in 1991 from the University of Valladolid. He then moved to a postdoctoral position at the Physics Department at the University of California, Berkeley, from 1992 to 1994. Between 1994 and 2001, he served as an Associate Professor at the University of Valladolid. In 2001, he was appointed as a Full Professor of Condensed Matter Physics and became the director of the Nano-Bio Spectroscopy Group. In August 2014, he accepted the position of Director at the Max Planck Institute for the Structure and Dynamics of Matter in Hamburg, Germany. Since 2017, he is Distinguished Research Scientist at the Simons Foundation's Flatiron Institute in New York, USA. He is renowned as one of the founders of modern "theoretical spectroscopy" and the creator of the widely used ab initio open-source project, Octopus. Recently, he developed the theoretical framework of "quantum electrodynamical density functional theory (QEDFT)," enabling the ab initio modeling of strong light-matter interaction phenomena in materials, ranging from non-equilibrium metastable states of matter to cavity-quantum materials engineering. His work has been recognized with several awards, including the 2018 Max Born Medal and Prize, the 2016 Medal of the Spanish Royal Physical Society, the 2014 Premio Rey Jaime I for basic research, the 2006 DuPont Prize in nanotechnology, and two European Research Council Advanced Grants. He is a Fellow of the APS, EPS, and AAAS, as well as a member of the Leopoldina Academy, BBAW, the European Academy of Sciences, the Academia Europaea, and the National Academy of Sciences (USA).*

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