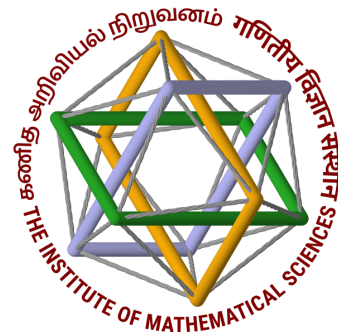# The Institute of Mathematical Sciences, Chennai

Quarterly Report

July - September 2019

Research Highlights

First PhD in Computational Biology

Established in 2013, the Computational Biology group is the youngest at IMSc and consists of an enthusiastic group of faculty, post-docs and students who work on a variety of interdisciplinary topics. Ankit Agrawal is the first student to complete a Ph.D in Computational Biology from IMSc, Chennai. He defended his thesis on July 18, 2019. His thesis advisors are Gautam Menon and Rahul Siddharthan. He worked on nuclear architecture with Gautam Menon and on the detection of transcription factor binding motifs with Rahul Siddharthan. After submitting his thesis, Ankit is a postdoctoral fellow at the Weizmann Institute of Science, Israel, and is working on biophysics and image analysis of cell packings.

Shanti Swarup Bhatnagar Prize for Dishant Pancholi

IMSc mathematician, Dishant Mayurbhai Pancholi was awarded the The Shanti Swarup Bhatnagar Prize for Science and Technology 2019 by the Council of Scientific and Industrial Research (CSIR). His research work is in contact and symplectic topology.

Application of Topology to Complex Networks

Topological data analysis (TDA) is an emerging field which employs tools from combinatorial and algebraic topology to study the *shape* of data. It reveals higher-order patterns within the data that remain hidden to classical methods of investigating the structure of data. High-volume data that emerges from large networks such as Facebook can be studied using TDA.

The main tool in TDA is *Persistent homology*, which has its origins in algebraic topology and is used to capture the global structures in a data set. Persistent homology is computed efficiently using discrete Morse theory, which is a combinatorial way of studying the underlying topology. An interdisciplinary collaboration between I. Roy in the Mathematics group and A. Samal in the Computational Biology group, along with H. Kannan (project assistant) of the institute has led to the development of a new method to investigate such higher-order structures in complex networks using TDA. The team has developed a new method to study persistent homology in unweighted networks based on discrete Morse theory. This method produces an efficient algorithm to obtain a discrete Morse function that not only helps to capture the higher-order relations in an unweighted network, but can also be used in the lossless compression of such data. This function is also used to compute the persistent homology of the network in an efficient manner.

The team has employed this new method to explore persistent homology of several unweighted model and real-world networks. They show that the persistence diagrams can distinguish between the topology of different types of model and real networks. A manuscript on this work appeared in the journal Scientific Reports.

Higson-Roe Sequence for Transformation Groupoids

Coarse Geometry investigates the large-scale structure of geometric objects. Building on earlier ideas of Gromov, Lawson and others, John Roe developed an axiomatic approach to study coarse structures (sometimes referred as uniform or bornological structures), with the goal of extending classical index-theoretic results on compact manifolds to the non-compact setting. A particularly striking application in the context of coarse geometry, is a K-theoretic generalization of a classical theorem of Gromov-Lawson on the index-theoretic obstruction for the existence of a metric of positive scalar curvature.

In collaboration with M. T. Benameur (Montpelier), I. Roy has extended the results of N. Higson and J. Roe on the construction of the analytic surgery sequence for discrete groups to the case of etale transformation groupoids. In particular, they generalize the Paschke-Higson duality theorem as well as new secondary index classes that are invariants of foliations and

laminations. In the process they develop a coarse analogue of a deep result of Pimsner-Popa-Voiculescu. Two papers on this area are scheduled to appear in the Journal of Noncommutative Geometry.

Euclidean Ideal Classes

In 1978, the Durch mathematician H. Lenstra introduced the notion of Euclidean ideal classes to study number fields with cyclic class groups. In particular, he showed that the class group of a number field with unit rank at least one is cyclic if and only if it has a Euclidean ideal class where the only if part is conditional on the Extended Riemann hypothesis.

In "On Euclidean ideal classes in certain Abelian extensions", a recent paper involving IMSc mathematicians S. Gun and J. Sivaraman and the French mathematician J-M. Deshouillers, an unconditional version of the above result for a family of Abelian extensions with unit rank at least 3 is established. This strengthens an earlier result of Murty and Graves.

It is an inherent feature of this theme that the number fields with small unit rank are more difficult to handle.

In another work, S. Gun and J. Sivaraman show that same assertion holds for a family of real cubic (respectively quadratic) fields with cyclic class groups with at most one (respectively two) exceptions.

Modular Forms

Suppose for all but finitely many primes p, we are given an elliptic curve E_p defined over a finite field F_p of p elements. In "Lifting of Elliptic curves", published in *Pacific J. Math.,* S. Gun and her Canadian collaborator R. Murty derive a criterion for the existence of an elliptic curve E defined over for which the reduction of E modulo p is isogenous to E_p for all p.

A Community Resource Documenting Experimental Evidence on Hormone-Disrupting Environmental Chemicals

A. Samal and his students have developed a digital resource called Database of Endocrine Disrupting Chemicals and their Toxicity profiles (DEDuCT) which contains a manually curated list of 686 Endocrine Disrupting Chemicals (EDCs) compiled from 1796 scientific research articles with experimental evidence in published literature on their endocrine disruption specific to human or rodents. EDCs are a group of chemicals of emerging concern omnipresent in environment that are known to cause adverse effects by interfering with the

human endocrine system. There has been growing interest in unraveling the endocrine disrupting mechanisms upon EDC exposure. In this direction, the research team has designed a detailed pipeline to identify such chemicals based on the experimental evidence in published literature. In addition, the team have compiled the adverse effects and the dosage levels at which each of these effects were observed upon EDC exposure. Subsequently, the EDCs were classified based on their type of supporting experimental evidence, their environmental source, and chemical classification.
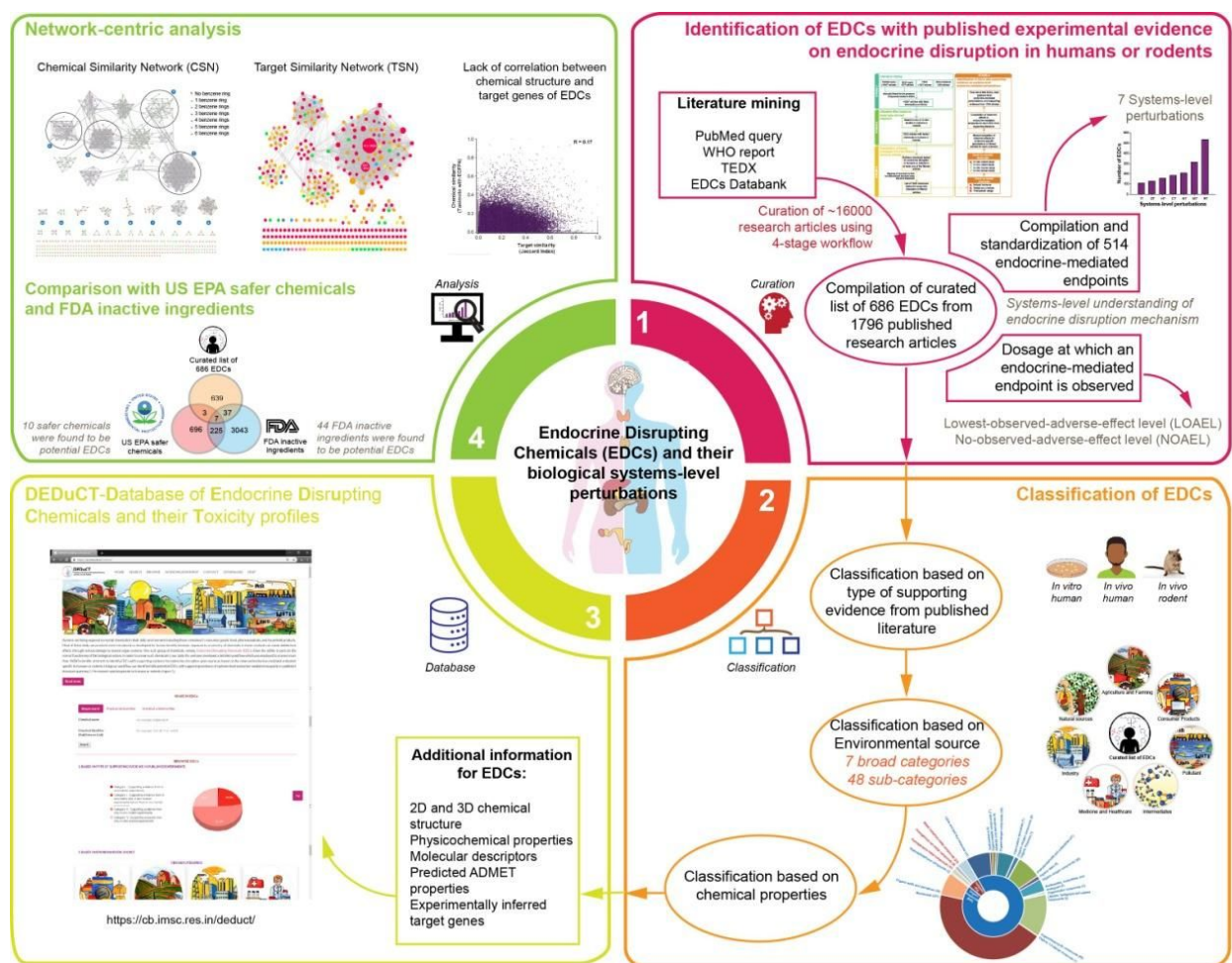
Schematic figure summarizing the work on endocrine disruptors

DEDuCT also contains information about chemical structure, physicochemical properties, molecular descriptors, predicted ADMET properties and target genes for potential EDCs. A network-centric analysis using DEDuCT revealed a lack of correlation between chemical structures and target genes of EDCs. In sum, this work highlights the future challenges in developing computational predictive models for adverse effects of EDCs. This large-scale

compilation on EDCs along with their endocrine-mediated adverse effects will facilitate future research on systems-level understanding of perturbations upon exposure. DEDuCT is freely accessible at

 https://cb.imsc.res.in/deduct/

This work was published in the journal Science of the Total Environment. Further the work has been covered by national and international media such as Hindustan Times, India Science Wire, ChemicalWatch, European Trade Union Institute and ACS Chemical & Engineering news.

Do we need a New Kind of Physics for Understanding Social Behavior ?

The enterprise of trying to explain different social and economic phenomena using concepts and ideas drawn from physics has a long history. Statistical mechanics, in particular, has been often seen as most likely to provide the means to achieve this, because it provides a lucid and concrete framework for describing the collective behavior of systems comprising large numbers of interacting entities. Several physicists have, in recent years, attempted to use such tools to throw light on the mechanisms underlying a plethora of socio-economic phenomena. These endeavors have led them to develop a community identity - with their academic enterprise being dubbed as "econophysics" by some. However, the emergence of this field has also exposed several academic fault-lines. Social scientists often regard physics-inspired models, such as those involving spins coupled to each other, as over-simplifications of empirical phenomena. At the same time, while models of rational

agents who strategically make choices based on complete information so as to maximize their utility are commonly used in economics, many physicists consider them to be caricatures of reality. A recent essay written by IMSc scientists S. Sinha and S. N. Menon, in collaboration with V. Sasidevan of CUSAT, which will be appearing in a book to be published by Springer shows that while these contrasting approaches may seem irreconcilable there are in fact many parallels and analogies between them. In addition, the scientists suggest that a new formulation of statistical mechanics may be necessary to permit a complete mapping of the game-theoretic formalism to a statistical physics framework. As the essay puts it, "This may indeed turn out to be the most significant contribution of econophysics''.

Novikov's Theorem in Higher Dimensions?

A foliation is an equivalence relation in a manifold whose equivalence classes are embedded submanifolds of codimension one. Novikov's theorem says that a taut foliation on a three-manifold does not have any Reeb components. Thus the class of taut foliations on three manifolds has a certain rigidity. For higher dimensional manifolds, the existence of a strong symplectic form has been proposed as an analog for tautness in order to achieve similar rigidity. It was conjectured (about ten years ago) that strong symplectic foliations would satisfy an analogue of Novikov's theorem. However, this turned out to be false, and in an article "Novikov's theorem in higher dimensions?" [arXiv 1907.05876] IMSc mathematician S. Venugopalan constructs a counter example.

Highlights of Outreach Activities

Facets: 8th - 9th July 2019

Facets is the Institutes's outreach program for advanced undergraduate and postgraduate students of mathematics. This two day program is intended for mathematics students to interact with professional mathematicians working in various fields. This year too, in addition to academics, the program featured mathematicians in industry as well as in the field of education.

The program also featured a career panel where students asked questions to panelists. This year, around 200 students attended this program.

Organizers: Sushmita V, Varuni P.

Speakers: Karen Haydock (HBCSE), R. Rajesh, R. Ramanujam, S. Sunder, Swarna Srinivasan (Ignite TCS), S. Viswanath, Vijay Ravikumar

Annular Solar Eclipse Planning Workshop: 20th - 21st July 2019

An Annular Solar Eclipse (ASE) will be visible on the morning of 26 December 2019 in India, with the annular track passing from southern Karnataka, northern Kerala through central Tamil Nadu. IMSc hosted a two-day workshop for institutions and organizations to plan outreach activities surrounding this Annular Solar Eclipse.

The mass campaigns during past solar eclipses in India are unique in their range and reach. This is a 2-day Nucleation Meeting on the ASE, for the southern states which will be in the path of the annularity. The workshop aimed to collate a list of resource material with responsibilities for their creation, translation and production (all under Creative Commons) and arrive at a shared set of strategies to get as many people as possible to see the eclipse safely. We hope that these plans will also be adapted for the ASE that will occur on 21 June 2020, whose path will cross northern India.

Organizers: Ramanujam R, Varuni P

Co-organizers: IMSc, Public Outreach and Education Committee of the Astronomical Society of India (ASI-POEC), Vigyan Prasar (DST)

Vigyan Pratibha Chennai Regional Teachers Workshop 2019-2020 I: 9th - 11th Sept 2019

IMSc organized a 3-day regional teachers workshop for the Vigyan Pratibha program, a Government of India program to nurture of talent in Science and Mathematics among VIII - X students. In addition to the resource people from Homi Bhabha Centre for Science Education (HBCSE), Mumbai, IMSc members also had sessions for the teachers. from The workshop was attended by 25 teachers from central schools (KV, JNV and AECS) in the southern region.

Organizers: R. Ramanujam, Varuni P.

Speakers: Chaitanya Ursekar (HBCSE), R. Ramanujam, Prateek Chawla, Rohini Karandikar (HBCSE), Subashri V, Swapna Narvekar (HBCSE), Varuni P.

Annual Solar Eclipse Planning meeting: 15th Sept 2019

A follow-up meeting for the Annular Solar Eclipse (ASE) planning attended by 20 resource people from the southern region.

Organizers: Ramanujam R

Co-organizers: IMSc, Public Outreach and Education Committee of the Astronomical Society of India (ASI-POEC), Vigyan Prasar (DST).