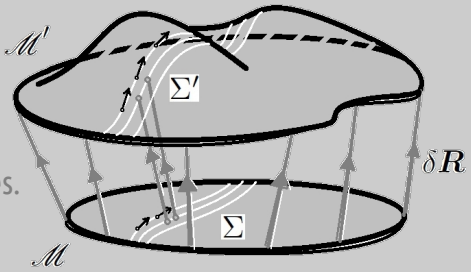
Research

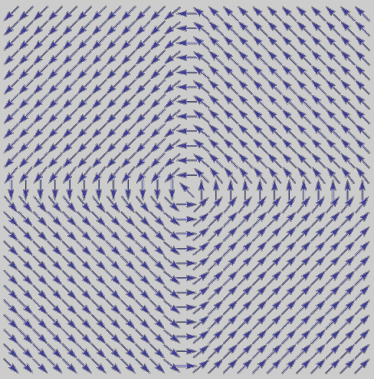
My principal research work involves ideas from the physics of liquid crystals, polymers, and membranes to study the interplay between geometry and topology of order and embedding shapes of surfaces. My neoteric foray into statistics has led to a resurgence in work related to machine learning and statistical mechanics.

• Equilibrium of fluid membranes with tangent-plane order (TPO), elasticity of smectic liquid crystals with TPO, and dispiration asymmetry in smectics-C*



Fluid membranes endowed with TPO (such as tilt- and hexatic order) afford unique soft matter systems for investigating the interplay between elasticity, shape, topology and thermal fluctuations. Using the spin-connection formulation for membrane- free energy we obtain equations of equilibrium together with free boundary conditions for the ground states of such membranes. We extend the spin-connection formulation to smectic liquid crystals with TPO and and show that for chiral smectics-C* this generalization leads to experimentally verifiable consequences for dispirations having topological indices of the same magnitude but opposite signs.

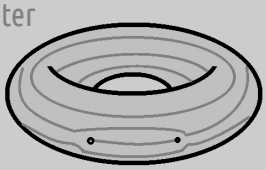
• Tent-morphologies of polymer crystallites

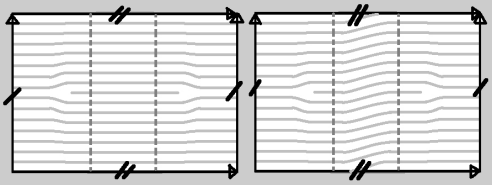


There is a significant difference between the growth of atomic crystals and polymeric crystals. Polymers are connected, whereas atoms and molecules are not. This leads to interesting consequences for the shape and morphology of polymer crystals. All the observed morphologies of polymer crystallites are lamellar in nature. These either show spherulitic structures composed of helicoids, or tent-like structures, or scroll structures.

We modify the Föppl–von Kármán theory of thin plates to account for (i) the fold-order, i.e. orientational order of polymer folds on the surface of lamellar polymer crystallites, (ii) anisotropy of line tension at crystallite edge. We obtain an exact intersecting kink (soliton) solution for the equations of equilibrium (corresponding to the modified plate theory) for a flat crystallite, and show that the flat crystallite buckles to form a tent that has a +1 disclination at its apex. Our results match the experimenatlly mapped fold-fields in tent-shaped crystallites.

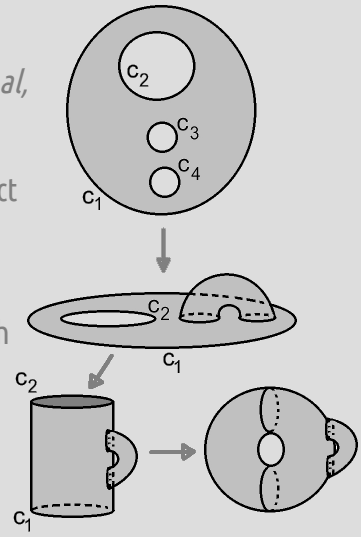
• Classification of crystal structures and topological defects in graphene nanotori and fullerenes with high genus





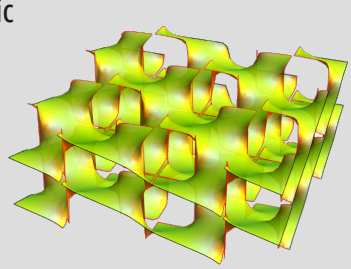
A carbon nanotube can be made by rolling graphene sheets into cylinders of ~1 nanometer diameter. Due to hexagonal symmetry of graphene, one can choose a range of rolling directions with respect to basis vectors of its lattice. This gives rise to different ground states. Experimental and theoretical analysis show that the mechanical and electronic properties of the nanotubes change drastically with the rolling direction. In addition to tubular structures, carbon nanotori have been observed experimentally and show high paramagnetic moments *(Lei Liu. et al, Phys. Rev. Lett. 88, 217206 (2002))*. This paramagnetic moment has been shown to depend critically on the crystalline structure. Thus, there is a

need to characterize and classify the different ground states of 2D crystals. In addition to nanotori it is possible that fullerenes with high genus can be synthesized *(Terrones et al, New J. Phys. 5 (2003) 126).*

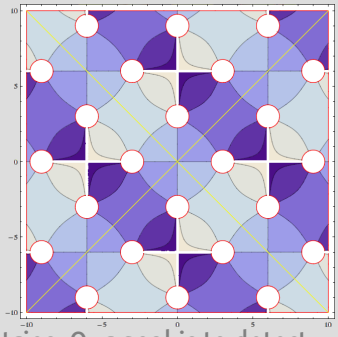


In this work, we classify the different ground states of crystalline order on closed, compact surfaces (without boundaries) of any genus. Our classification scheme is not based upon homotopy theory. We adopt foliation theory (ribbon graphs) *(Anton Zorich, eprint arXiv:math/0609392)* from dynamical systems, and extend the idea of Dehn twist to tori and higher genus surfaces with crystalline order. To classify such crystalline surfaces (with and without topological defects) a unique ribbon graph represents a given crystalline configuration of fullerenes with arbitrary genus. The ribbon graph also provides a mechanism by which one can generate a class of distinct ground states.

- Phases, morphologies, and transitions in a mathematical model for the endoplasmic reticulum



Recent experimental studies on the rough endoplasmic reticulum in cells indicate the presence of screw dislocations. We propose that the pressure is reponsible for inducing screw dislocations in endoplasmic reticulum. Critical pressure to induce nucleation of single dislocation and a centered square lattice of oppositely charged screw dislocations are estimated in linear theory. Further we investigate the effect of non-linearity on the phase diagram, numericaly, using Surface Evolver code. A detailed phase diagram with tubules, fenestrations, lattice of holes and the screw dislocation lattice are being explored.

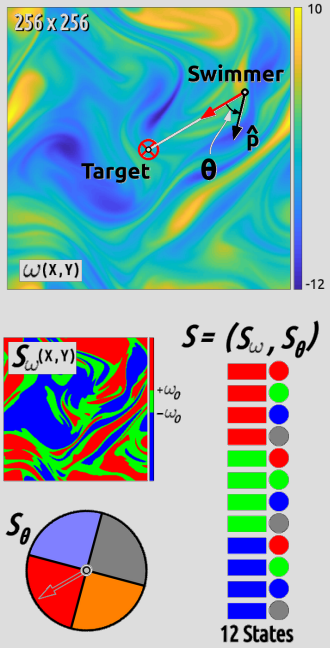


- Economy of academic research: *with Rahul Pandit (IISc)*

We investigate the economy of academic research by studying different models of funding agencies across countries. We use Scientometric and econometric measures to compare and rank the performance of research organizations of the different countries. Our goal is to detect economic factors that affect the academic output efficiency.

- Machine learning in turbulent flows

We explore the prospect of using machine-learning methods to optimize the transport properties of passive self-propelled Lagrangian particles in homogeneous isotropic turbulent flows. In particular, we use Q-learning, a form of reinforced machine-learning technique, to develop optimal schemes of propulsion to maximize the number of particles that arrive at a target in a fixed time. Preliminary results on arrival time statistics show that the performance of Q-learning depends on the period in which the learning is operational. If the Q-learning and particle evolution are initiated simultaneously, for short time scales the rate of particle arrival at the target is higher than the naive strategy; but this scheme performs poorly in comparison to the naive strategy over long time scales. On the other hand, we observe for a few numerical trials, that the particle arrival rate can be enhanced by delayed learning or re-initializing the Q-matrix at later times.



- Machine learning to control spatio-temporal chaos in cardiac arrhythmia

The aim of developing a low amplitude defibrillation scheme to eliminate pathological waves, in the heart, is of central interest in the clinical field. In this article, we report that, we make use of the deep learning technique such as the convolution neural network (CNN) to train all possible wave solutions in an excitable media to accurately detect spiral and non-spiral waves. Furthermore, we utilise the trained CNN model to generate a heat map of positions of spiral core/cores in spiral waves/broken spiral waves which is central to our new defibrillation scheme. Using the positions of spiral core we can eliminate the local spiral waves by applying a local defibrillation current of 2D Gaussian profile in a squarre lattice. With our new scheme, we report that, we have successfully eliminated broken spiral waves in silico.