Statement of Research Interest

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My research interest lies in the intersection of physics, biology and computational science.

The scope of phenomena that can be studied within the confines of Physics has expanded in the last several decades thanks to the advances in computational research. In the pursuit of comprehending basic processes in nature, computer simulations can serve as a valuable supplement to experimentation. One key area where computational tools have shined the brightest is the investigation of the fundamental Physics that underlies many of the fascinating events in soft matter using conventional molecular simulations. It covers the phase behaviour, non-equilibrium behaviour, and response of soft materials, such as colloidal suspensions, polymers, and surfactants, to non-homogeneous environments. Large strides have been made in understanding the equilibrium and non-equilibrium behaviour of many large-scale statistical systems with complex interactions using techniques such as Monte Carlo simulations, molecular dynamics, Langevin dynamics etc. which would have been impossible to do so otherwise.

Throughout the duration of my undergraduate studies, while engaging in the computational studies of statistical systems such as Boltzmann gas particles, Domains of ferromagnets, Suspension of particles in media etc., I observed that a large and diverse number of biological phenomena can be studied and explained using simple statistical physics models. While working on my first internship project on the Ising model of ferromagnets, I was intrigued to learn the same model with minor changes can also be used to study the collective behaviour of fish swarms. Thenceforth I discovered several applications of physics-based modelling of biological systems spanning direct applications such as protein folding using Coulombic and Van der Waals's interactions between molecules and the study of cytoskeletal structures using principles of mechanics and fluid dynamics as well as indirect applications such as analysis of bird flocks using nearest neighbour interactions, modelling prey-predator relations using asymmetric interactions, clustering of bacterial swarms using Brownian motion etc.

At present, I am very interested in studying the collective motion of active matter. Active matter is a collection of active agents which consume energy to exert mechanical forces (E.g. bird flocks, bacterial colonies, active gels etc.). Due to the active energy of the agents, these systems are inherently out of equilibrium and break time-reversal symmetry. Several statistical physics-based models are used to study and analyse the behaviour of active systems (most notably the Vicsek model) and the universality of such models is still being explored. One of the most appealing aspects of active matter is the emergence of collective behaviour. Under particular conditions, certain active systems are capable of exhibiting ordered movement and behaving as a single unit without the use of any central coordination network but rather simply by coordinating with their neighbouring agents. Examples of such behaviour found in nature include flocking of birds, clustering of bacteria, bundling of microtubules etc. Another specific feature I am intrigued by is the observation of non-reciprocal interactions in certain systems. Non-reciprocal interactions refer to interactions which seemingly breaks Newton's third law of action-reaction symmetry. Notable examples of such interactions are prey-predator relations, bacterial swarming in the presence of chemical gradients, cytoskeletal interactions etc. These interactions break the principle of detailed balance which intrinsically throws the system out of equilibrium. This could lead to a multitude of interesting and complex behavioural patterns for the system.

I am deeply interested in understanding such systems, creating interaction-based physics models for the same and using computer simulations to evolve, observe and analyse emergent behaviours. I am also open to the incorporation of artificial intelligence and machine learning models into the construct for more effective simulation of complicated interactions as I have considerable experience in the use of deep learning tools in tackling biological problems.