Research Statement

My scientific research is broadly in the realm of information science. Two distinct themes are elaborated below, viz., **(i) wave turbulence**, that is crucial for understanding of information pertaining to climate and weather phenomena, thereby of direct relevance to our daily lives; and, **(ii) dynamics of complex systems**, that has broad applications in generating new paradigms in technology and information exchange spanning quantum computation to design of new materials.

Research Themes

My expertise is in multiple-scales perturbation theory and computational modeling of complex dynamical systems. Accordingly, the following are a list of research problems that are of interest to me currently.

1. **Wave turbulence and fluid dynamics modeling**: The role of wave dynamics in fluid turbulence is pivotal. Recently, this aspect has been investigated by me in the case of fast rotating turbulent flows and the theory is published in the peer-reviewed journal **Fluids**,[1] the paper can be accessed from my research page or by searching the web-identifier: `doi:10.3390/fluids2020028`. I am interested in extending the scope of this work in several practical applications in climate, geophysical and astrophysical context. This will bear close collaboration with the climate research community and broaden our understanding of wave turbulence.

   The role of symmetries involved in various fluid dynamics systems and their spontaneous breaking (coinciding with wave breaking) is another close line of research that I have been working on in the context of two-phase follows captured by the Cahn-Hilliard model. This study is potentially a powerful way of parametrizing the onset of turbulence in fluid flows, at least in the multi-phase case. Preliminary simulations demonstrating this phenomenon can be found on my research page under the section 'Multi-phase flows': `https://amriksen.wixsite.com/amriksen/scientific-research-amrik-sen`

2. **Hamiltonian dynamics of complex systems**: Complex dynamical systems are ubiquitous. Of particular interest to me, is the emergence of aperiodic order in nature, where the translational periodicity (symmetry) is broken in a natural way. In this context, I have recently developed a Hamiltonian model and tested it computationally for the one-dimensional case. Results of the simulations for the 1D case are available on my youtube channel referenced on the page: `https://amriksen.wixsite.com/amriksen/scientific-research-amrik-sen`. Currently, I am developing the model in two-dimensions that will be extended to three-dimensions in future. Methods used in this approach are based on statistical mechanics, computation of partition functions and transition amplitudes, analyzing the configuration space of the model as well as building and running Monte-Carlo simulations of the new Hamiltonian architecture.

   I am also interested in studying the algebraic language that describes this phenomena in the lines of spectrum generating algebra and/or non-commutative algebra. In this context, I would keenly look forward to close collaborations with Mathematicians (algebraists and non-linear dynamics specialists) to foster this line of research that will be crucial to deeper understanding of emergence of aperiodic order. A useful introductory reference on aperiodic order is the book by Baake and Grimm[2] and the text by Barber,[3] the latter discusses several practical applications of aperiodic structures in condensed matter physics.

Research Methods

My research involves both theoretical techniques from diverse fields in mathematics, eg., perturbation theory, asymptotics, and building numerical models in computers.

Amrik Sen
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[1] **Amrik Sen**, *Anisotropic Wave Turbulence for Reduced Hydrodynamics with Rotationally Constrained Slow Inertial Waves*, Fluids, 2017, 2, 28.

[2] **Michael Baake** and **Uwi Grimm**, *Aperiodic Order: A Mathematical Invitation*, Cambridge University Press, 2013.

[3] **Enrique M. Barber**, *Aperiodic Structures in Condensed Matter*, Taylor & Francis, 2009.

Research questions and importance

The above listed research themes aim to address the following research questions of interest to a broad area of science.

Wave turbulence and fluid dynamics modeling

1. How can climate and weather models better incorporate non-linear wave and turbulence effects in climate prediction models?
2. What is the precise role of wave dynamics and turbulence in planet formation?
3. How does energy transfer happen between wave modes and turbulent modes? How does entropy calculations in turbulent flows broaden our understanding of information flow in away from thermal equilibrium systems?
4. How can our understanding of symmetry breaking in parameter space broaden our understanding of dynamical systems?
5. What are the computational challenges in developing a turbulence and fluid dynamics solver which have immense industrial applications in automotive industry, lubrication and petroleum industries, pharmaceutical industries, financial engineering, etc ?

Hamiltonian dynamics of complex systems

1. How can Hamiltonian mechanics and mathematical modeling help us in developing new paradigms in quantum computing?
2. How can *empire* patterns in aperiodic systems capture non-local interactions in dynamical systems and broaden our understanding of several non-linear phenomena in nature?
3. What is the most appropriate computational algebra for studying aperiodic systems?

Research resources and future outlook

To accomplish the above research projects, the following computational resources will be necessary.

1. Initiation of a program to build high performance cluster computers that will meet the intensive computing needs. These clusters will be the work-horse for massive parallel computations that will serve as a corner stone for building new technology and meet 21^{st} century skill requirements for such technologies among the student and faculty community of the institute.
2. The inter-disciplinary nature of the above projects will foster a cross-departmental and cross-university collaboration among students and researchers. This will prepare the students better in terms of their industrial skill requirements that will be beneficial during their job placements. Such inter-disciplinary research will immensely enhance the reputation and credibility of the institute.

Expertise

The author of this research plan has many years of expertise in mathematical modeling, including several years of hands-on experience with super-computers and algorithms, that is necessary to execute the research plan.

Amrik Sen.