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Research Interests : **Extreme events, Data driven modeling, Private algorithms, Machine learning**

Education :

Indian Institute of Science Education and Research, Pune
Ph.D. in Physics Under the Supervision of Prof. M.S. Santhanam
2019-2024 (Expected) — CGPA : 9.5/10

Jawaharlal Nehru University, New Delhi
M.Sc. in Physics
2017-2019 — CGPA : 7.3/9

Ramakrishna Mission Residential College, Narendrapur, Kolkata
B.Sc. in Physics(Hons.), Chemistry and Mathematics
2014-2017 — 74.88%

Nekursuni Krishi Silpa Siksha Sadan, Bamanbarh, Purba Medinipur
Higher Secondary, WBCHSE
2012-2014 — Aggregated : 86.6%

Nekursuni Krishi Silpa Siksha Sadan, Bamanbarh, Purba Medinipur
Secondary, WBBSE
2012 — Aggregated : 92.57%

Skills :

Programming Languages : Python, C, C++ Fortran, JavaScript

Markup Languages : LaTeX, HTML

Programming Skills : Object Oriented Programming, Parallel programming with OpenMP, Data structure and Algorithms

Languages : Bengali, English and Hindi

Scholarships :

National Talent Search Examination Scholarship — 2010-2012

INSPIRE Scholarship — 2014-2019

Prime Minister Research Fellowship — 2021-2024(expected)

Teaching Assistant: Nonlinear Dynamics (Spring 2021), Course coordinator: Prof. M. S. Santhanam
Computational Physics (Fall 2021) and (spring 2022), Course coordinators: Prof. Apratim Chatterji and Prof. Prasenjit Ghosh

Lecturer: Mathematical Methods in Physics (Fall 2021), at Fergusson college, Pune

Electrodynamics (Spring 2022), at Fergusson college, Pune

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Introduction

My broad research interest can be summed up as the study of complex systems. Specifically, I am interested in gaining insights into the problems at the interface of physics and social science. Gaining insights from real-world data, we model those problems mathematically and further analyze them using the tools of statistical physics, graph theory, and computation. This report will describe the problems I worked on during the last review period and highlight the significant results we obtained. The following is a brief outline of the three projects I explored.

- **Bursting echo chambers by random nudge:** We show that by nudging people to make random interactions, the effect of echo chambers in social media can be significantly reduced, which leads to depolarization in opinions. As large nudge strength leads to the undesired effect of radicalization, we formulate an optimization problem to find the optimal fraction of the population to be nudged and the optimal nudge strength.
- **Extreme events: ratios of recurrence time:** We analyze ratios of the recurrence time of consecutive extreme events. We find that the distribution has a fractal nature and it can be modeled by a generalized Thomae function. Further, we analyze the same for the Indian temperature time series and find an excellent agreement with the analysis done for the synthetic data.
- **Universality in voting behavior:** We study the election data of several countries and find universality in the ratio of the votes received by the winner and the runner-up. In particular, the distribution of the ratios follows either a stretched exponential or power-law.

Bursting Echo Chamber by Random Nudge

The information revolution has lowered the entry barrier for nearly everyone to participate and contribute towards shaping opinions and even policies on various issues. This has been largely aided by the easy availability of social media infrastructure through mobile devices. However, these kinds of institutions are often the birthplace of echo chambers, which refers to the scenario in which one person's opinion is similar to that of the persons in their "social neighborhood," and one tends to reinforce the other. This is often the breading ground of misinformation, polarization, and extreme behavior. In a recent model, the empirical phenomena of echo chambers and polarization in the dynamics of opinion formation are realized by promoting homophily, the tendency to interact with people of similar opinions. In this project, we introduce a novel framework to nudge people non-intrusively to form a random connection which significantly decreases the echo chamber effect and reduces the polarization in opinion while keeping the diversity in opinion intact. The framework of nudge is the following:

Basic framework: The model considers N interacting agents, whose opinions on a topic of interest are denoted by $x_i (i = 1, 2, ...N)$, which can take any real value in the range $(-\infty, \infty)$. The sign of the x_i corresponds to the agent's stance, and $|x_i|$ denotes the agent's conviction in their stance. The interaction network co-evolves with the agents' opinions. At each time step, the active agents form connections with other agents based on the interaction probability P_{ij}, which is defined to be a function of the magnitude between two agents' opinions

$$P_{ij} = \frac{|x_i - x_j|^{-\beta}}{\sum_j |x_i - x_j|^{-\beta}} \ , \tag{1}$$

where β, the homophily factor, quantifies the tendency for agents with similar opinions to interact with each other. The opinion dynamics is given by the following N coupled differential equations.

$$\dot{x}_i = -x_i + K \left(\sum_{j=1}^{N} A_{ij}(t) \tanh{(\alpha x_j)} \right), \tag{2}$$

where K is the social interaction strength, α is the controversialness of the topic, and $A_{ij}(t)$ is the adjacency matrix of the temporal interaction network.
Intervention: To burst the bubble of echo chambers, we introduce the following intervention by modifying the interaction probability,

$$\widetilde{P}_{ij} = p \times \frac{1}{N-1} + (1-p) \times P_{ij}, \tag{3}$$

where p is the nudge strength. This intervention can be seen as a recommender engine, which recommends random connections in a social media platform.

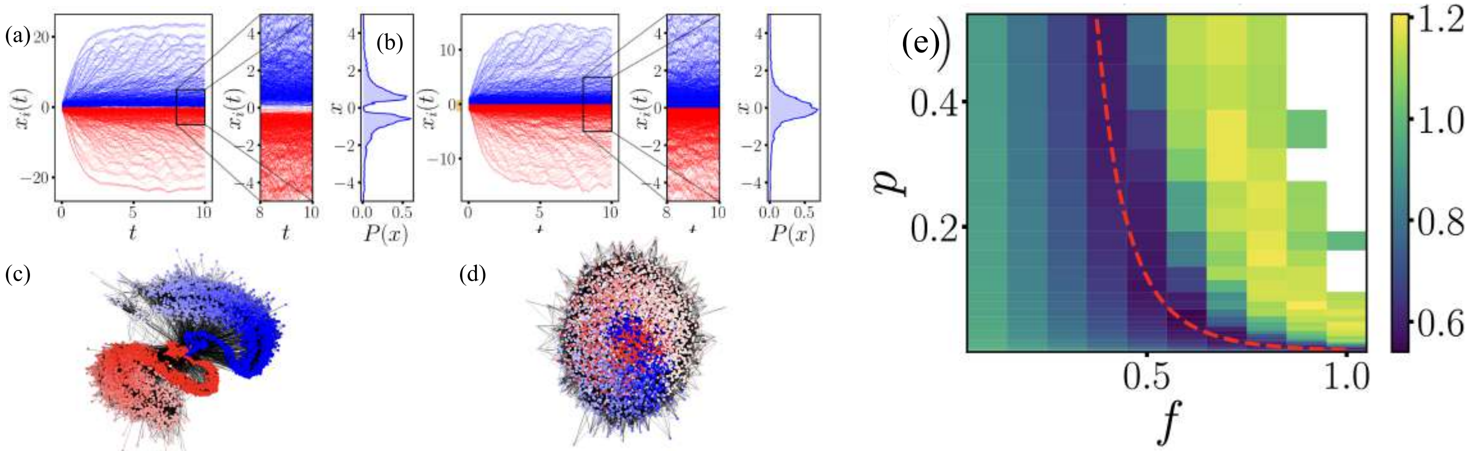

Figure 1: Depolarization of opinion under random nudge.

Result: With the intervention strategy introduced above, we find that with sufficiently small random nudge probability p can lead to significant depolarization in the opinion distributions characterized by a uni-modal distribution. Fig. 1, panel (a), shows individual agents' opinions trajectories, along with the final bi-modal distribution of polarised opinions. Panel (b) shows that the opinion distribution is depolarized in the presence of a nudge $p = 0.01$. Panels (c) and (d) show the difference in network structure between polarised and depolarised systems. The network structure of depolarised (due to nudge) system is well mixed; hence it decreases the effect of an echo chamber. There is an undesired effect of radicalization (all agents having the same stance) when the nudge strength is large. We formulate an optimization problem to avoid polarization and radicalization. Panel (e) shows the curve for nudge strength (p) and the fraction of agents (f) that minimizes the utility. The optimal curve has the form $p \cdot f^A = B$ (A,B are constants).

A detailed account of our motivations and results can be found in our manuscript available here. As discussed above the undesired effect of polarization can manifest in society, by the formation of echo chambers. This often lead to extreme opinions and behaviors among people. This is one of many examples of "extremes" found in natural, man-made systems or in society. In the next project we thoroughly analyze a new facet of extreme events in more generalized setting.

Extreme Events: Ratios of Recurrence Time

Extreme events, defined as events whose numerical values differ significantly from the values of typical events and exceed a predefined threshold, often disrupt the system's functionality. Hence the study of extreme events gained the attention of researchers over the last few decades. In this work, we extensively study the distribution of ratios of consecutive recurrence times of extreme events in simulated and empirical time series data.
Methods: We considered time series with exponential auto-correlation functions, often known as weakly correlated time series, for a comprehensive numerical study. An event in the time series is "extreme" if it exceeds some predefined threshold value q. The recurrence time ($s_i = t_{i+1} - t_i$) is the time gap between $(i+1)$-th and i-th extreme events. As the sampling frequency of the time series is constant s_i's are essentially scaled integers, bounded above by the length of the time series. We define the ratio of the consecutive recurrence time as ($R_i = \frac{s_{i+1}}{s_i + s_{i+1}}$), which can take rational values from the range $(0, 1)$.

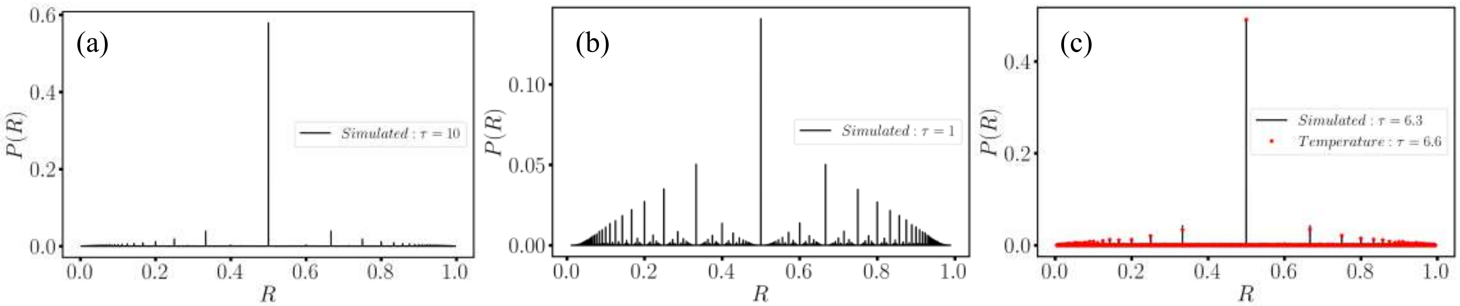

Figure 2: $P(R)$ vs R for simulated time series and temperature data.

Results: Upon extensive numerical investigation, we find that the distribution of ratio $(P(R))$ is symmetric around $\frac{1}{2}$, and fractal in nature (Fig. 2). We find the peaks at small denominator fractions prominent for the time series with large correlation lengths(τ). Moreover, the peak at $\frac{1}{2}$, corresponding to three extreme events with equal recurrence time, is the most prominent. The height of these peaks at small denominator fractions decreases, and the distribution's box-counting dimension increases as the correlation length(τ) of the time series is decreased. Fig. 2 panels (a), (b) show the difference in $P(R)$ for time series with τ. We also find $P(R)$ to have a special form, which we call generalized Thomae function

$$P_\tau\left(R = \frac{a}{b}\right) = \frac{1}{f_\tau(b)}; a < b \, and \, GCD(a,b) = 1. \tag{4}$$

To show the applicability of our results in real-world time series, we calculated $P(R)$ for the historical temperature data of Rawalpada, Maharashtra ($20.5^o N$, $73.5^o E$). As shown in Fig. 2 panel (c), the distribution from temperature data matches the distribution from simulated time series, having similar correlation lengths(τ).

We describe our results and demonstrate their applicability in real-world data-sets in this manuscript. We find that the fractal-like distributions of ratios are not specific to the above extreme event problem. From biological data-sets, to election data, the ratios of whole numbers seems to have a fractal-like distribution. In the project discussed bellow we find fractal behavior in vote share distribution for few countries.

Universality in Voting Behavior

Election, one of the main pillars of democracy, is a large-scale social experiment. In this project, our goal is to build a comprehensive model of the voting process, which will capture the universal features found in real-world elections and form a benchmark to detect fraud in elections.

Methods and results: In this voting process, we assume that there is n_i number of candidates in a constituency i with N_i number of eligible voters. Each voter casts their vote for one candidate. After the voting process, the candidate with the most votes is declared the winner, and the candidate with the second most votes is the runner-up. We define ratio $R = \frac{W}{L}$, where W is the number of votes received by the winner and L is the number of votes received by the runner-up. Analyzing several countries' election data, we find that the ratio distribution $P(R)$ either takes the form of a stretched exponential or a power-law. We also find that for elections where the number of voters in each electoral unit is relatively small, the distribution of vote fraction received by a particular party has a similar fractal-like form found in the extreme event project.

Conclusion

In the last review period, I worked on three main projects, which all fall under the broad umbrella of socio-physics. The manuscripts for the opinion dynamics and extreme event projects is available here 1,2. In the third project related to democracy and elections, we found universal features in voting. We plan to extend this project to make a model that can help us detect election fraud. Ultimately we plan to build a tool that will aggregate data in a deferentially private manner and predict the "mood of the nation" using NLP and other models.