The Game of Self-interest vs. Social interest: Estimating Effective Strategic Interventions against COVID-19 with Stochastic Networks and Behavioural Games

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PI Expertise: Mathematical modelling of complex systems, Data-driven predictive computational models of real systems, Time series analysis, Statistical physics and complex networks.

Objectives: Since its first identification only five months back, Coronavirus disease 2019 (COVID-19) pandemic shook the world with the number of infections growing beyond 20 lakhs worldwide. Indian government took rapid intervention steps by implementing travel restrictions, quarantines, curfews, event postponements, facility closures and lock-down. The effectiveness of these intervention policies depends utterly on the participation of people, both healthy and exposed. In practical scenario, individuals in a society under a threat of epidemic spread, decide independently whether or not to follow an intervention policy and health guidelines, and thus, a complicated interaction between the disease spread, the social connections and individual decisions occur, which is hard to extrapolate without help of a computational predictive model of epidemiology coupled with game theory and network simulations. The goal my mathematical epidemiological study will be first to recognize the causes of spreading of a communicable disease, then formulate a model to understand the nature of its course, and finally to predict ways of controlling it. In order to estimate the effects of individual decisions on the overall epidemic spread, this decision-making has to be represented as a separate game-theoretic component of a model. Finally, as COVID-19 is highly infectious, and our country has patches which are suffering from high rates of infections, an optimum testing algorithm terms of will be incorporated using reinforcement leaning, to understand and predict the control parameters and devise strategies.

Methodology and expected outcome: The dynamics, evolution and control of COVID-19 is intimately connected to epidemiological, human behavioural dynamics, and testing processes that operate across multiple spatial and temporal scales. These complex dynamics along with the rapid spread of COVID-19 are demanding for innovative modelling methodologies that can successfully and coherently accommodate three key elements: infectious disease dynamics, social interaction and information flow, and the decision-making of individuals. With my expertise in this field[1], I will derive optimal strategic behaviour using a disease network game.

The work-flow, along with outcomes of each phase is discussed below:

1) This project will first focus on a stochastic network disease game model that captures the behaviour of individuals during the spread of a susceptible-exposed-infected-quarantined-recovered (SEIQR) disease.
2) On a complex network, individuals will be allowed to strategically modify their behaviour based on self-interests, driven by both truthful news and rumours.
3) A combination of epidemiological diffusion and collective dynamics of community networks will be integrated keeping spatial movement of individuals in account.
4) Considering relevant and practical parameters, like an infectious 'tail'[2] with infected, delay in detection of asymptomatic exposed, a 'cost' associated with being voluntarily self-quarantined and a game of self-interests, I will formulate a model that addresses the realistic situation of COVID-19 outbreak.
5) Reinforcement learning has been proved efficient in many challenging learning tasks, specifically, in the problems where direct supervision is not possible. Framing the problem of efficient testing in a population to find out the exposed and infected people as a game, I am planning to implement task-aware deep-Q reinforcement learning for maximum efficiency.

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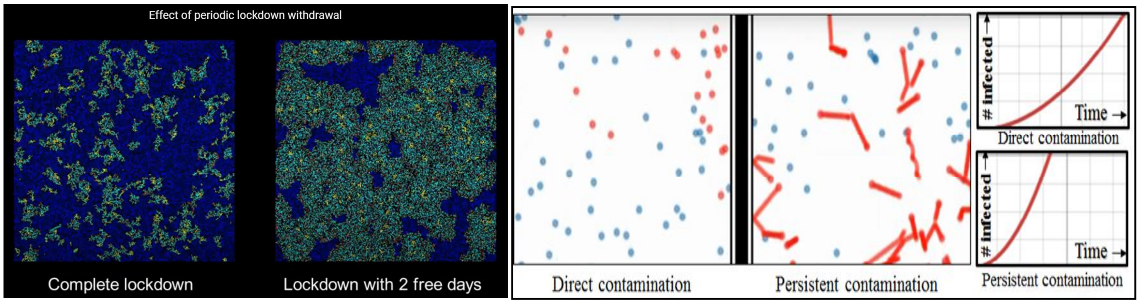
[1] • K Gaurav, S Ghosh, S Bhattacharya, YN Singh, accepted in Scientific Reports (Nature), 2020. • S Bhattacharya, S Ghosh, K Gaurav, Physica A, 525, 2019. • K Gaurav, S Ghosh, S Bhattacharya, YN Singh, IEEE TENCON, 2017



(a) (b)

Figure 1: (a) Effect of periodic lockdown withdrawal with only few days of relaxation. (b) Slow movement and voluntary social distancing reduces infection rate significantly. Refer to video 5 (social distancing with slow movement) of [2].

6) My model will be completely driven by data, where relevant parameters like infection rate, death rate, migration probabilities, endemic threshold $\Re_0$ will be fed into the model from the real-time data, to address the questions of interventions strategies and predict their effects.

I have already started implementing some of the major observations related to COVID-19, and found exceptional agreement with data[2] which I have disseminated among people for spreading awareness; some snapshots of the performed *computational experiment in support of 'Janta curfew' and lockdown extension* has been illustrated in Fig 1. In this time of need, a concrete and extensive computational study addressing the impact of information flow through social connections, game of interests and risk-aversion methods is the only way to identify and quantify the proper intervention strategy to COVID-19 dynamics.

Budget	
Budget Head	**Amount**
GPU workstation for large-scale spatial simulation and RL implementation	3 lakhs
Web domain	0.5 lakhs
Contingencies	0.5 lakhs
Total	**4 lakhs**

Related publications of PI in last 5 years

i. "Non-genetic heterogeneity, criticality and cell differentiation", Physical biology, 2015, 12 (1), 016001.
ii. "Equilibria of Rumor Propagation: Deterministic and Network Approaches", IEEE Region Ten Conference, 2017
iii. "Viral Marketing on Social Networks: An Epidemiological Perspective", Physica A, 525, 2019.
iv. "Bifurcation and Criticality", Journal of Statistical Mechanics: Theory and Experiments, 2019.
v. "Classification of RBC and WBC in noisy microscopic images of blood smear", SPIE Conference on Information, Photonics & Communication, 2019.
vi. "Ensuring the Spread of Referral Marketing Campaigns: A Quantitative Treatment", Accepted for publication, in Scientific Reports (Nature).

[2] https://saumikb.github.io/epidemiology101/