Estimating Latent Fields in Stochastic Dynamical Systems - A Case Study of COVID-19 in New Mexico

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ABSTRACT

We will demonstrate a method, involving Markov random fields (MRF) and variational inference (VI), to infer a latent spatiotemporal field that drives a stochastic dynamical system. The method will be predicated on limited and noisy observations. Specifically, we will show how case-counts of COVID-19, collected in the counties of New Mexico (NM) during the early epoch of the pandemic, can be used to infer the spread-rate field of the disease, while preserving the spatiotemporal correlations in the data.

Climate change will increase the risks of pandemics, as animal hosts migrate to more hospitable areas and encounter naive human populations [1]. The sustainable way to address this risk is to detect and control the outbreak in remote, sparsely populated areas (e.g., the desert counties of NM) before it reaches population centers. As the COVID-19 pandemic showed, it is possible to collect and distribute simple data e.g., case-counts, quickly and reliably, though the data might be "gappy", with high variance errors. Detecting outbreaks with such low-quality data is difficult.

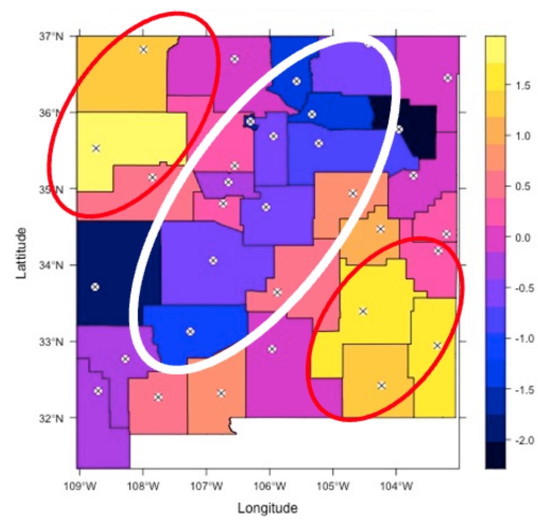

Figure 1: Spatial correlations observed in NM's COVID-19 data. The "blue" counties along the Rio Grande valley show similar dynamics, while the deserts in the Southeast and Northwest (yellow) behave very differently.

Our approach is based on the hypothesis that the (latent) spread-rate of a disease is a better monitoring variable for disease detection, as it depends on population mixing patterns that do not vary erratically. We construct a disease model, with a $K-$dimensional parameterization of the spread-rate, for each areal unit (i.e., a county; Ref. [2]). A joint inference of the spread-rate across N counties implies a $N \times K$-dimensional inverse problem that must maintain the patterns seen in the data (Fig. 1). This is performed using a VI technique, with spatial correlation being imposed with a parameterized MRF model. We will demonstrate how the inferred spread-rate can be used to detect new outbreaks (the fall wave of 2020) and avoid false positives, and compare its performance againsta conventional outbreak detector.

REFERENCES

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[2] C. Safta, J. Ray, and K. Sargsyan. Characterization of partially observed epidemics through Bayesian inference: application to COVID-19. *Computational Mechanics*, 66:1109–1129, 2020.