Intensive Collaborative Work on COVID-19 Modeling

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1 Introduction

This is a story of a COVID-19 modeling collaboration between two scientists who live at a considerable distance and who have been collaborating since 2017. They are developing several novel ideas to understand the spread of the epidemic. They work closely at developing, planning, and policy-making decisions.

The broader subject of mathematics and the subject of quantification are centuries old and these have been of great value not only for theoretical developments but appreciated for their positive roles in society. This includes understanding planetary motions as well as other useful ideas in ecology and environmental studies. However, mathematical ideas have been also in use for understanding the propagation of the number of people infected and the spread of epidemics since the 18th-century cholera epidemic in Europe, the 20th-century plague epidemic in England and India, the Spanish flu epidemic in the U.S. and other countries, and for several infectious diseases like HIV/AIDS, avian influenza, etc.

Modeling the novel coronavirus (COVID-19 or SARC-nCov2) since it has been reported from mid-December 2019 in China has very particular characteristics. Several modeling experts across the world and other people working on quantification of epidemics are studying the matter from several different points of view. The ensuing results could range from

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(i) the uncertainty of the virus genomics, and its etiological properties,
(ii) the uncertainty of what will be best treatment options if infected,
(iii) how to contain the virus within an infected area,
(iv) level of infectivity,
(v) list of all clinical signs and symptoms,

and so forth. Even in the initial days (late December of 2019, early January of 2020) it was not clear whether the virus would be spreading to other countries outside China. There were even suppositions that, if the virus reached the U.S., then it could be easily contained.

The authors began by asking the following question: how do we construct wavelets (a kind of improved version of the Laplace transform from harmonic analysis) based on an epidemic from only partial information on that epidemic? The goal was to be able to construct a complete picture of an epidemic from partial information. We developed rigorous mathematical methods while addressing these questions and published our first paper in the *Journal of Theoretical Biology* [1]. We accelerated our preparation of this article from January–February, 2020 as we started to realize the importance of the methods developed due to the emergence of COVID-19, and we focused as well on the novel coronavirus during the revision of our manuscript when it was accepted in March, 2020. Our further collaborations on corona started very quickly as we have engaged in intensive study of the development and applications of various mathematical and probabilistic techniques.

In this article, we will describe a collection of ideas we are developing for COVID-19 in the U.S.A., Europe, and Asia. Note that several new mathematical ideas have been explored and developed, which range from simple differential models to detailed age-structured models to wavelets. We also look at set-theoretic and Venn diagram expressions, conformal mapping principles, Fisher-Rao metrics, etc.. We will describe how our quantifications assisted in practical planning and also describe how we collaborated so intensively within the span of a few months. Our activities have included articles published/prepared, grant proposals written, invitations to give talks, mini-symposia, peer-review requests, special issues of journals, etc..

2 Under-Reporting of COVID-19

First, we have published studies on the pandemic covering several countries. Just before our first paper got accepted, we decided to study the under-reporting of corona in various countries until the first week of March. Such an idea was a natural consequence of our first paper. In this study, we have constructed a simple differential equation model with two variables—those who are particularly susceptible to the virus and those who have a virus. Our model tries to obtain numerically the number of newly infected cases in each country from the day that a country has reported more than ten cases until the first peak that occurred [2, 3]. We had to calibrate the parameters of transmission based on the reported trend and from growth in reported cases.

In addition, other factors such as population density, people living in urban areas, population age-structure, etc., were also considered. This study received attention worldwide as this was the first model-based under-reporting that considered a detailed parameter. Once the projected new cases were obtained through the model, we have compared them with the reported cases with the same data to obtain the rate of reported cases to the total number of cases. Such a ratio was plotted through Meyer wavelets, which are very flexible structurally and robust too. The notable feature of wavelets is that they are localizable both in the space variable and the phase variable.

These wavelets helped us to visually see the difference between actual cases of corona as per the model and the reported cases of the corona. What we predicted until the end of March (either predicted to be severe or not) turned out to be true for several countries, for example, Italy, Germany, Spain, South Korea etc.

Other countries that we considered were China, India, France, Iran, the UK, and the U.S.A. We have also analyzed the data on general health preparedness of rich countries and the status of COVID-19 response during the first two months of the pandemic [4].

Apart from the papers mentioned above which published our under-reporting-related research, our work has attracted the attention of 40–60 worldwide newspapers (both print and OnLine) and TV channels in several languages. Details of the matter can be found through Internet searches. It was a great experience for us to communicate the various questions from the media and devise our mathematics—either the wavelets or the differential equations or detailed modeling assumptions—to simplify to a language that can be understood by non-experts. After all, science is meant to be implemented and communicated to help society!

3 ICU and Non-ICU Admissions in the U.S.A.

We have visualized a collection of sets of populations to understand the spread of COVID-19 with and across these sets. Some of the sets within the collection are mutually exclusive and some have overlapping populations. We have also divided these sets further based on whether the populations within each set have any medical underlying conditions like hypertension, cardiovascular illness, lung diseases, and combinations of these diseases. The idea was to use these sets to predict what fractions of these sets of people with underlying conditions in the U.S. population who are aged 65+ will likely have COVID-19 during April–June, 2020, and to find how many of them within the collection will likely be hospitalized [6]. We further provided the number of hospitalizations that required ICU (Intensive Care Unit) admissions and those which do not. We developed age-structured models for prediction and considered wavelets for understanding the difference in magnitudes of various sets of predicted populations with COVID-19.

4 Social Distancing

We have considered the degree of lockdowns and social distancing in our age-structured type of models, combined with wavelets to predict the number of new cases that could emerge during the months of May–June, 2020 [5]. One of the novel features of this work is that we have considered new cases of COVID-19 that were identified and those that were not identified. Among those that were not identified, we have varied the degree of adherence to the social distancing norms to predict new transmissions within the U.S.

5 Virtual Tourism Technology and Information Geometry

Because of the pandemic, the airlines, hospitality, and tourism industries have been financially affected. Considering the need of the hour, we have proposed to develop a new technology called LAPO (live-stream with actual proportionality of objects). This technology, if developed and implemented, proposes to use mathematical and statistical principles such as Fisher-Rao metrics and Rao's distances and conformal mappings for maintaining consistency between visual distances and angles of objects in actual tourist locations and that of 2D images and 3D videos [5]. Such applications of information geometry principles and angle preserving techniques and the related technologies are novel to the literature. A related concept is referred to as the Fisher-Rao metric. Our LAPO concept will make travel accessible and safer for more people, and will be fun for young and old.

6 Timely Assistance Provided in Planning and Response

Through our collaborations, we have had an opportunity to assist in timely planning and preparing COVID-19 responses at various levels. For example, we received an invitation from the Governor's office through the university to provide Georgia state-level predictions in March 2020. Again, in April 2020, we received a request to provide dates at which the model-based peaks of COVID-19 cases in Georgia and for a couple of counties would occur. Local media and TV reported these results, see for example (WRDW, April 14, 2020, Augusta Chronicle, April 4, 2020). We have also assisted the Bulgarian Academy of Sciences when their President of the Academy approached us for providing model-based predictions of national COVID-19 numbers. Our results were used by their national preparedness team. We have also received several requests to give Webinars, mini-symposia, invitations for peer-review from leading journals, invitations to write articles, and of course received lots of appreciation and support from our respective universities. We both are also co-editing a special issue on the theme Wavelets, Dynamical Models, and Algorithms in Understanding and Preparedness for the COVID-19 Pandemic for a reputed journal in mathematics, namely, the *Journal of Mathematical Analysis and its Applications*.

7 Artificial Intelligence Frameworks

One of us (Rao) has been involved in developing artificial intelligence frameworks for identifying the coronavirus cases and implementing the technologies through the hospital systems and mobile-based surveys [7]. Such ideas received wide media attention of 150–170 news outlets across the globe as that was the first idea proposed for identification of the COVID-19. One can search on the Internet for all media reporting of this work. Through the probabilistic approach proposed in their work, it is possible to construct probabilities of identifying a person with certain disease symptoms.

8 Rewards of Distance Collaboration in the Time of COVID-19

Rao's background is in mathematical and stochastic modeling analysis and Krantz's background is in theoretical mathematics (mostly complex analysis). We bring very different perspectives to this work. The result has been a rewarding collaboration and a strong new personal friendship.

As described in Figure 1, we have made use of the mathematical, statistical, and probabilistic techniques in a timely fashion and worked rigorously with a passion to be able to assist in the COVID-19 response.

Of course, neither of us is a stranger to distance collaboration. Krantz has more than 60 co-authors all over the world, and Rao has about a dozen. But it is new to both of us to have a meeting of minds between a medical school and a theoretical mathematics department. The COVID-19 virus has played an elemental role in making this happen. The shared concern and the shared passion for making a difference have been a driving force for both of us. Practicing applied mathematics that can save and improve people's lives is certainly a worthwhile endeavor.

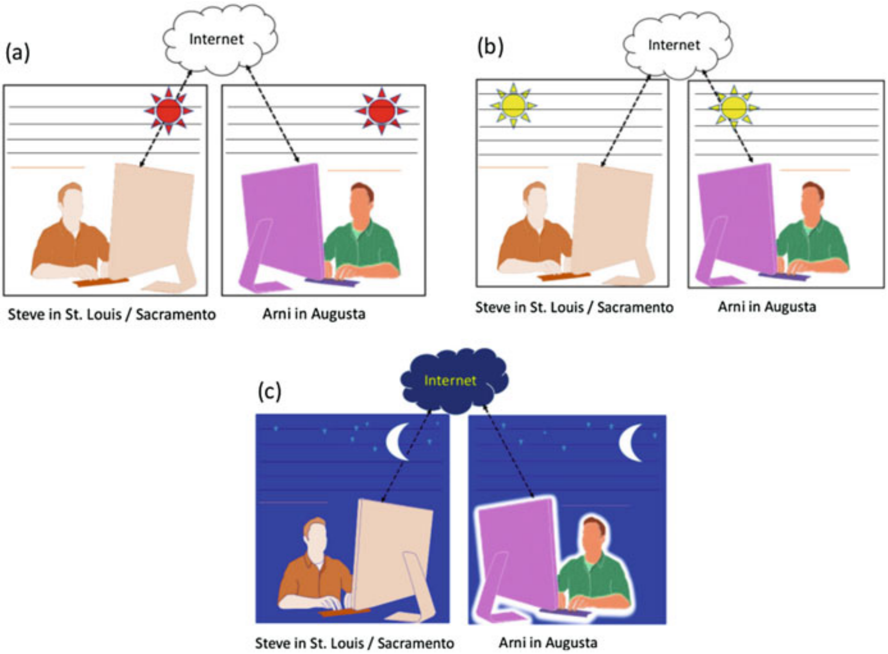

Fig. 1 Krantz and Rao collaborating long distance and long hours.

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(Photo taken by Kim Ratliff)

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(Photo taken by Randi Diane Ruden)