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Quantifying COVID-19:
Modeling and Evaluation

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Certificate of Original Authorship

I, *Qing Liu* declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the *School of Computer Science*, *Faculty of Engineering and Information Technology* at the University of Technology Sydney. This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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Abstract

The coronavirus disease 2019 (COVID-19) has evolved to a global pandemic and poses significant demands and challenges in modeling its complex epidemic transmission, infection, and contagion. Moreover, it has shown to be vastly different from known epidemics. To address the COVID-19 pandemic, significant efforts have been made to model COVID-19 transmission, diagnoses, interventions, and pathological and influence analysis, etc. However, due to the unique and unknown problem and data complexity, the related studies of COVID-19 still face numerous challenges, including undocumented infections, asymptomatic contagion, uncertainty and quality issues in the reported data, flexible external non-pharmaceutical interventions, unknown resurgence patterns or periodicity, and multiple mutations.

This thesis aims to understand COVID-19 concerning the COVID-19 research landscape, transmission complexity, non-pharmaceutical interventions, and COVID-19 resurgence. Focusing on the COVID-19 challenges, this thesis first compares the key characteristics of COVID-19 disease with several known epidemics, and it summarizes the COVID-19 modeling complexities caused by these attributes. Starting from this basic knowledge, this thesis further explores COVID-19 modeling, which results in the following four contributions. (1) This thesis tracks the current COVID-19 modeling progress with natural language techniques and statistically summarizes the major facts of COVID-19 disease and COVID-19 modelling. This work structures a transdisciplinary research landscape and provides a holistic picture of COVID-19 modeling. (2) It infers the possible quantity of undocumented infections in the early stage of the COVID-19 outbreak with the proposed density-based Bayesian probabilistic compartmental model. This work examines the COVID-19 transmission complexities, in other words, undocumented infections, contagion reinforcement, and the imperfect conditions existing in COVID-19 reported data, that is, noise, sparsity, and uncertainty. (3) With the proposed event-driven generalized Susceptible-Exposed-Infectious-Recovered compartmental model, this thesis studies the impact of external interventions and activities in the dynamic COVID-19 evolving process and quantifies the efficacy of control policies and relaxation measures. (4) This thesis compares the differences between multiple COVID-19 waves, including the epidemiological attributes and the countermeasures, and it simulates the possible scenarios with different interventions and virus mutations. This exploration illustrates the possible reasons for COVID-19 resurgence and provides reliable guidance for society resuscitation.

Extensive experiments, including mean-field Bayesian inference, backward-looking

empirical evaluations, forward-looking simulations, and short-term forecast, demonstrate the effectiveness of the proposed methods for modeling the COVID-19 complexities aforementioned. The findings and quantitative results in this thesis indicate clues, evidence, and guidance for governments and policymakers to appropriately manage and mitigate the COVID-19 pandemic.

DEDICATION

To my beloved parents, Zhenhai Liu and Yuhuan Cheng ...

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List of Publications

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1. Liu Q, Do T D T, Cao L. Answer Keyword Generation for Community Question Answering by Multi-aspect Gamma-Poisson Matrix Completion[J]. IEEE Intelligent Systems, 2020.

2. Hou W, Liu Q, Cao L. Cognitive aspects-based short text representation with named entity, concept and knowledge[J]. Applied Sciences, 2020, 10(14): 4893.

Under review or submission:

3. Cao L and Liu Q. COVID-19 Modeling: A Review[J]. arXiv preprint arXiv:2104.12556, 2021. submitted to Machine Learning (submission ID: MACH-D-21-00689).

4. Liu Q and Cao L. Modeling COVID-19 uncertainties evolving with time and density-dependent social reinforcement and asymptomatic infections[J]. arXiv preprint arXiv: 2108.10029, 2021. submitted to Scientific Reports (submission ID: 2e67d7c3-4b47-4f49-ae8c-c9f03924caa3).

5. Cao L and Liu Q. How control and relaxation interventions and virus mutations influence the resurgence of COVID-19[J]. medRxiv, 2021. `https://www.medrxiv.org/content/10.1101/2021.08.31.21262897v1`, to be submitted.

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