Assignment 13: Agent-Based Modeling Applications

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The outbreak of COVID-19 in late 2019 and early 2020 was swift and global. In short notice, countries, cities, and towns had to decide how they were going to respond. A variety of non-pharmaceutical interventions (NPIs) came to the forefront: economic lockdown, school closures, quarantining, social distancing, masks, and contact tracing, to name a few. How these strategies might affect the progression of the disease and the socioeconomic fabric of societies was an open question, its answer ultimately dependent on a multitude of variables pertaining to the biological features of the disease and the combination of strategies applied. Due to a lack of historical data on how pandemics progress in our modern world, predicting these sorts of outcomes was a difficult problem.

Agent-based modeling (ABM) proved to be a useful methodology for predicting these outcomes and comparing the relative efficacy of various NPIs. A literature review performed by Priest, Timberg, and Mekhennet in December of 2020 found hundreds of papers that had already applied ABMs to predicting COVID-19 activity. The design of these models shared common themes: 1) Societal populations were modeled as collections of agents in a network or geospatial environment with behavior and contact networks defined by demographic characteristics. 2) The presence and spread of COVID-19 was represented as a probabilistic state model and defined by parameters such as rate of spread and death. 3) Various agent behaviors and model parameters were implemented to represent the presence of interventions, the final simulated disease outcomes being compared to test their relative efficacy. (Priest, Timberg and Mekhennet 2020)

The most well-defined models represented societal agents as nodes in a network, in spatial dimensions relative to one another, or both. Two specific papers, *Modeling COVID-19 for lifting non-pharmaceutical interventions* by Koehler et al (Assignment 12) and *Covasim: An agent-based model of COVID-19 dynamics and interventions* by Kerr et al modeled society as networks in manners representative of others in the literature review. In these models, agents were prescribed demographic characteristics such as age, marital status, health status, profession, and educational enrollment in distributions supposedly representative of society. Networks among these agents are then formed based on household, professional, educational, and communal relationships.

Through each iteration of the model, agents go about their daily routine, going to work, school, and engaging in communal activities. In addition to demographic data, each agent has a health status that is tracked through time. To varying degrees of complexity, these health statuses represent COVID-19 in a compartment epidemic model, the main statuses being not sick, sick, and then either dead or recovered (Priest, Timberg and Mekhennet 2020). Features of the disease, such as rates of contagion, relative severity likelihood, and death rates are parameterized. More complex models feature states that include different severities of illness, asymptomatic cases, different rates of contagion by age group, incubations periods, and even viral load. Through each iteration, these probabilities are applied through each interaction, and the health status of each agent is updated. Aggregate statistics of agents' health statuses at each iteration indicate the societal progression of the disease throughout the simulation.

Interventions to COVID-19 were modeled differently in different papers. The three basic methods that were employed were representing interventions as changes in the environment, agent behavior, or parameter values. For example, a lockdown could be represented by halving the number of professional, educational, and communal networks in the environment, or a hybrid work schedule could be represented by professional networks meeting every other day, or a vaccine could be represented by a change in the probabilities of transmission. These methods allow for comparative simulations that may demonstrate relative efficacy of tested interventions.

Historically, the most common modeling method for epidemics has been compartmental models. In these models, populations are modeled at a particular size, with individuals progressing through disease states (not sick, sick, dead/recovered) with a set transmission rate between individuals at each period. Such models are useful as they can provide an understanding of how different transmission rates affect disease outcomes in a population. Relative to these models, the agent-based models proposed by Kerr et al, Koehler et al, and those in the literature review provide advantages. Primarily, they are able to model a much higher degree of environment and agent behavior and complexity. While compartmental models assume that each individual in a population is homogenous, agent-based models allow for heterogeneous agent and disease behavior. This allows for both a deeper understanding of how disease features and agent behavior affect health outcomes, as well as for better predictive power. In fact, agent-based models were actively used in policy-decision making in numerous instances of COVID-19 response. (Priest, Timberg and Mekhennet 2020) For example, Covasim, the ABM platform created by Kerr et al, was fit to King County, Washington's demographic data, then used to simulate a variety of NPIs, the output of which influenced the ultimate policy decision.

Agent-based modeling is not without its weaknesses. Inherent in both of the referenced individual papers' models were assumptions about how COVID-19 functions that were unrealistic. It should be noted that these criticisms also apply to compartmental models and, presumably, a subset of those in the literature review. For example, it is assumed by setting recovered as a terminal state that reinfection is not possible. Priest, Timberg and Mekhennet also noted that implicit in many definitions of interventions was that there would be a homogeneous response to the implementation of interventions, which would not be the case in the real world (take masks, for example.) Their literature review also provided noteworthy statistics on the use of real data in their surveyed ABM papers. Just over half employed the use of any real world data, and even fewer had any form of model validation. (Priest, Timberg and Mekhennet 2020)

Despite these limitations, ABMs proved themselves useful for responding to COVID-19 by having an impactful influence on policy design. Features of the best projects mirrored those of our best modern technologies: open-source code, documentation, real-world data for model design, parameter tuning, and validation, expert consultation, and published works. Despite the existential threat the pandemic posed, it provided a rich opportunity for applications and literature of ABMs.

References

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