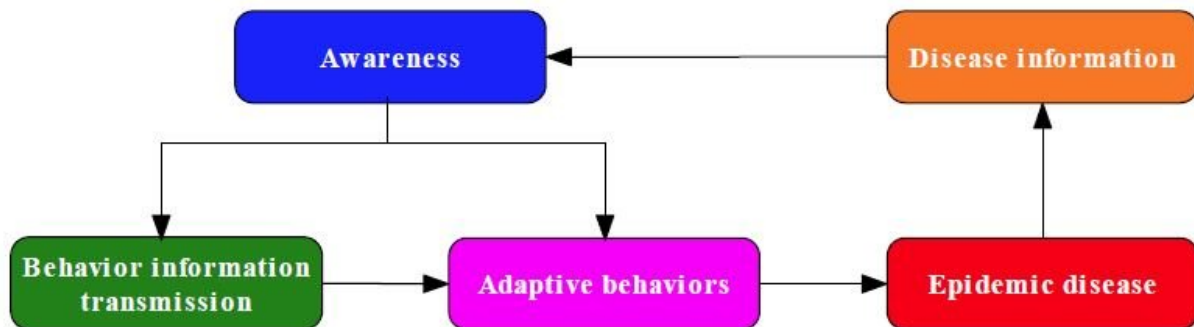


Network theory links behavioral information flow with contained epidemic outbreaks

June 14 2018



A specific logical loop in the process of the construction of the concrete interplay model. Credit: Mengfeng Sun, Michael Small, Shui Shan Lee, and Xinchu Fu

Over the last two decades, large-scale outbreaks of infectious diseases have resulted in high levels of morbidity, mortality, and overall economic burden for affected regions. As complex networks become increasingly popular tools of study, researchers are applying network theory to the field of epidemiology. Due to the plethora of disease-related data available from various media outlets, an individual's behavioral response to and communication of an epidemic depends on the pattern of information flow in a separate yet related network. As a result, mathematical models of humans' reactions to disease outbreaks are important tools in epidemiological analysis.

In an article publishing next week in the *SIAM Journal on Applied Mathematics*, Mengfeng Sun, Michael Small, Shui Shan Lee, and Xinchu Fu employ a concrete interplay [model](#) in quenched multiplex networks to study the connection between adaptive human behavior and epidemic spread. They base their model—which illustrates these factors as separate layers in the networks—on a standard susceptible-infected-susceptible model. Its generality makes it applicable to a wide range of [public health](#) scenarios.

Members of an affected population typically base their behavioral responses on information gleaned from mass and social media, physical encounters in their social and spatial neighborhoods, and general observations. "Traditionally, infectious disease models have treated [human behaviors](#) as constant, implying that they do not fluctuate according to disease incidence or a characteristic timescale," Sun and Fu said. "However, the development of modern technology offers a great convenience for the communication of human behaviors, including face-to-face conversations, email exchanges, phone calls, and other types of interactions in a variety of network forums." Humans adopt preventative measures based on these direct or indirect relations, both to protect themselves from infection and reduce the risk of further disease transmission. Such measures include limitation or elimination of time spent outside the home, increased attention to hand-washing and personal hygiene, and limited contact with neighbors and other citizens.

Prior studies involving complex interplay models have classified awareness into three categories: local awareness, global awareness, and contact awareness. However, Sun et al. classify it into two alternative categories: (i) adaptive behaviors stemming from awareness and (ii) behavioral information transmission (the spread of awareness itself). "Our work is within the framework of network-based models, and we use a more accurate network configuration—quenched multiplex networks—to model the transmission of an infection," Sun and Fu said.

"This configuration involves the interplay of epidemic spread, information transmission, and behavioral dynamics." The authors configure these multiplex networks into two layers. One layer accounts for recurring physical contacts, such as coworkers, family members, friends, classmates, and neighbors; interaction with these groups can spread infection. The second pertains to virtual contacts—acquaintances on Facebook, Twitter, or other online social networking platforms; communication with this group is not physical and thus cannot actively spread infection.

When people become aware of an epidemic, [adaptive behavior](#) and behavioral information transmission occur concurrently, with transmission spurring continued adaptation. For the purposes of their model, Sun et al. focus on adaptive behavior's effect on infection rate. Individuals' disease-related communication steadily modifies behavior until it reaches an optimal protective state. Such behavior is a result of the spread of information pertaining to the epidemic, rather than the epidemic itself. It tends to be consistent or herd-like, as people communicate protective behaviors with their neighbors more frequently when an epidemic manifests in order to protect themselves. A higher adaptive strength correlates with a lower risk of infection.

"By taking account of multiple dynamic processes simultaneously, our model not only accurately describes the actual spread of epidemics in complex networks but also characterizes the interactions between the transmission of some epidemics (like the common cold, seasonal influenza, dengue fever, Zika, etc.) and the corresponding human behaviors," Sun and Fu said. "We also find that behavioral control for some individuals enhances the speed with which the epidemic tends to become stable and the speed of collective synchronization, and also significantly reduces the value of the highest peak of the infection's prevalence. This suggests that our epidemic control strategy from the perspective of behavioral control is very valid."

To test their model, the authors apply it to an outbreak of severe acute respiratory syndrome (SARS), a contagious and dangerous respiratory illness. Because no vaccines currently exist for SARS, public health measures are primarily responsible for its control. Sun et al. focus on two types of minor [preventative measures](#) from the most recent outbreak: transmission precautions (i.e., use of protective equipment—like gloves—and attention to personal and environmental hygiene) and contact precautions (minimization of time spent in public spaces). An individual's decision to adopt these measures depends on the outbreak's severity. The authors create a mathematical model that includes SARS transmission, behavioral evolution, and regulation of public institutions. Every individual in an affected area is assigned one of four possible states: susceptible, asymptomatic, symptomatic, or recovered.

"The analysis suggests that a rapid behavioral response, a combination of public health measures, and the regulation of public institutions for certain key individuals (those with more connections) can effectively curb the outbreak of SARS by decreasing cumulative infections and deaths and reducing the reproductive number," Sun and Lee said. Preventative behaviors were especially effective during the epidemic's early stages, and achievement of the optimal preventative state for all individuals led to rapid containment. Ultimately, both pharmaceutical and nonpharmaceutical measures were responsible for total control.

Because manufacturers cannot immediately make vaccines or targeted drugs available at the onset of an epidemic, governments, public health authorities, and/or mass media typically advise the population on the appropriate measures for optimal self-protection and reduced susceptibility or infectivity. Citizens' increased awareness of adaptive behavior's power gives researchers and doctors time to make vaccines and treatments available.

"The numerical results show that individual adaptive behaviors triggered

by the emergence of an epidemic can slow down the spread of the infection, lower the final epidemic size, and in some cases can prevent the infection from becoming widespread," Small said. "These results provide us with an alternative idea on understanding why some infections do not cause major outbreaks or reach the [epidemic](#) threshold in the absence of immunization policy or territory-wide quarantine and isolation measures."

Sun et al. hope to incorporate realistic data about human behaviors to formulate more practical and applicable models. They plan to specifically investigate the effects of drastic control measures—such as isolation, vaccination, and treatment—and the impact of the time delay between when individuals become aware of an outbreak and when they modify their behaviors. Until then, their current model identifies several methods through which individuals can protect themselves and their neighbors from emerging epidemics.

More information: Sun, M., Small, M., Lee, S.S., & Fu, X. (2018). An Exploration and Simulation of Epidemic Spread and its Control in Multiplex Networks. *SIAM Journal on Applied Mathematics*. To be published.

Provided by Society for Industrial and Applied Mathematics

Citation: Network theory links behavioral information flow with contained epidemic outbreaks (2018, June 14) retrieved 23 April 2024 from <https://phys.org/news/2018-06-network-theory-links-behavioral-epidemic.html>

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