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Photo cropped on the top and bottom.

Math Societies to Lawmakers: Networks Critical in Our Interconnected World

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Biannual Briefings

The American Mathematical Society (AMS) Office of Government Relations (<https://www.ams.org/government/government>)—jointly with the Mathematical Sciences Research Institute (MSRI)—sponsors two congressional briefings per calendar year.¹ These briefings provide an opportunity for the mathematics community to impart information to policymakers and, in particular, to tell compelling stories of how federal investment in basic research in mathematics pays off for the American taxpayer.

On June 13, in the Rayburn House Office Building on Capitol Hill, contagion spread. It propagated outward from patient zero, 2017–19 AAAS Science and Technology Policy Fellow Catherine Paolucci, immediately affecting AMS Associate Executive Director Karen Saxe, MSRI Director David Eisenbud, NSF DMS Director Juan Meza, and former US Representative Bart Gordon (D-TN), among others. Continuing transmission overtook the author of this text, and soon those seated near her.

But then, to the seeming surprise of Cornell University computer scientist Jon Kleinberg, the spread stalled.

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¹For coverage of the December 2018 briefing, see the April 2019 Notices: <https://www.ams.org/journals/notices/201904/rnoti-p584.pdf>.

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With Paolucci's consent (and acknowledgment that his former student Johan Ugander pioneered the activity), Kleinberg had simulated the contagion in order to explore the social network connecting the nearly 100 attendees of the first joint AMS/MSRI congressional briefing of 2019, "Addressing Threats and Vulnerabilities in Critical Interconnected Systems: Common Principles in Disease Outbreaks, Internet Malware, and Bank Failures." First he had instructed anyone who knew Paolucci to stand, then anyone who knew anyone who was already standing to stand, and so forth, until no one sitting down was acquainted with anyone standing up.

"The cascade runs for a while, but when it stops the boundary of that cascade reveals something about some separation within the network that we may want to look at, remedy, connect," Kleinberg said. "We hope that some of you who are sitting down and some of you who are standing up get to meet each other as a result of this event."

Jon Kleinberg attributes the success of LinkedIn to a successful cascade.

Interconnected systems undergird our modern world. The language of networks, which describes any structure comprised of a set of objects (*nodes*) linked in some way (by *links*), captures phenomena of interest to everyone from civil engineers and operations researchers to economists and sociologists, Kleinberg said. "Any time we're looking at patterns of linkage, we're looking at a network."

A network may exist in the physical world—metro stations and the tracks between them, transmission lines and the power plants they connect—but can also be more abstract: Financial institutions make loans to one another and people are joined by familial ties, friendships, shared alma maters. Social media platforms have made large quantities of social network data readily accessible, and a perhaps surprising amount of information can be gleaned from even a cursory examination of the patterns of connections therein.

"At the center here is one Facebook user who in this case donated their network to science so we could look at it here," said Kleinberg as he displayed a slide showing a constellation of dots with a web of lines connecting numerous pairs of them. Various friend groups—classmates, coworkers, relatives—formed dense clouds of interconnectedness, but one node stood out for having links to many of these otherwise disparate cliques.

"That turns out to be their spouse," said Kleinberg.²

With networks as ubiquitous as they are, it is in our best societal interest to understand how harm can come to them. Kleinberg addressed two primary mechanisms by which problems spread through networks: transmission and unraveling.

The first of these is familiar from epidemics of communicable diseases like HIV or measles. Epidemics in the

²The observation that "spouse detection" is a tractable computational problem for social networks originates in [1].

virtual world—computer viruses—are also nothing new, but today's malware has more in common with biological pathogens than ever before: it has gone airborne. The wireless connectivity of, for instance, short-range Bluetooth connections means your computer can get a virus just by being near an infected machine. Kleinberg reported that mathematical models developed to study human disease epidemics are being repurposed to give insight into these new sorts of short-range malware attacks.

Transmission is harm propagating through a network; unraveling is the cascading breakdown of the network itself. Nodes can break—banks can fail, species can go extinct—but so can links. If a tree downs one transmission line, rerouted electricity may overload others, causing further failure and potentially the collapse of the entire power system.

While we'd like to avoid power blackouts, economic and ecosystem collapse, and global pandemics, sometimes we *want* a cascade. Maybe we want to spread the word about an upcoming election or start some buzz about a business we're launching.³ Or perhaps we want as many people as possible to get a flu shot.

It turns out that certain critical nodes can be key in both preventing undesirable cascades and promoting desired ones. Consider, for instance, an oft-used tactic for promoting widespread flu inoculation: encouraging people to "bring a friend to get your flu shot." Having a friend along may provide needed moral support for the needle-anxious, but Kleinberg said that such campaigns have "an extra sort of network component" too.⁴

If everyone brings a random friend along to the clinic for the shot, someone with twice as many friends is twice as likely to get vaccinated. And the person with twice as many friends is precisely the kind of person you *want* to have a flu shot, since he or she is more likely to be spreading the flu to lots of people. Even without anyone mapping out the network of flu-spreading interactions, then, the bring-a-friend campaign effectively targets its critical nodes.

While one line of research looks at how to promote beneficial cascades, another—still nascent—seeks to identify warning signs of harmful ones. If you're trying to anticipate when a divisive bit of fake news might go viral or when a financial system might spiral into disarray, there are features of the relevant network structure—small patterns called *motifs*—that promise, once more thoroughly understood, to inform prognostication. "How many collections of three nodes form a triangle?" researchers ask. How many pairs of nodes form a bidirectional link? How many collections of four nodes form a complete cluster? Each of these counts is a possible measure of network vulnerability.

³Many a successful online platform, for example, owes its success to a cascade. "You can think of the spread of LinkedIn in its first few years as an example of a very successful—and deliberate—global outbreak," said Kleinberg.

⁴This idea was first written about in [2].

Kleinberg talks to NSF Division of Mathematical Sciences Director Juan Meza.

"What you find often when the network is experiencing the beginnings of a crisis, some of these measures start to change dramatically," Kleinberg said. "The hope is that if we can find the ones that are good signals we could detect things early on."

Kleinberg began his talk by commending funding agencies for recognizing the power of multidisciplinary research, thereby catalyzing fruitful activity that could not have been accomplished by any one discipline alone. He concluded by reiterating that it takes a joint effort to model complex systems; to identify the components most in need of protection; and to predict, promote, or guard against cascades.

"There's an opportunity for really valuable collaboration between the mathematical sciences research community, computational engineering, social sciences, and the funding agencies that have really generously funded this work and also brought areas together that haven't been talking to each other," Kleinberg said. "I think there's really a lot of prospects for important work on this going forward."

What You Can Do

You, too, can help get the word out about the importance of funding basic research:

- Write a letter to your senator or representative.
- Write an op-ed for a local publication.
- Organize a talk at your institution about the unexpected utility of basic math. Invite your representative and work with your school's government relations office.
- See the AMS Office of Government Relations' "Tools to take action" page (<https://www.ams.org/government/dc-prepare>) to get started.

References

- [1] Backstrom L and Kleinberg J, Romantic Partnerships and the Dispersion of Social Ties: A Network Analysis of Relationship Status on Facebook, *Proc. 17th ACM Conference on Computer Supported Cooperative Work and Social Computing*: 831–841, 2014. arXiv:1310.6753
- [2] Cohen R, Havlin S, and ben-Avraham D, Efficient Immunization Strategies for Computer Networks and Populations, *Physical Review Letters*, (91): 247901, 2003. Online at <https://bit.ly/2Rt5Iuw>

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Credits

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