

Using the friendship paradox to sample a social network

When applied to random nodes in a network, the statement "Your friends have more friends than you do" has predictive power.

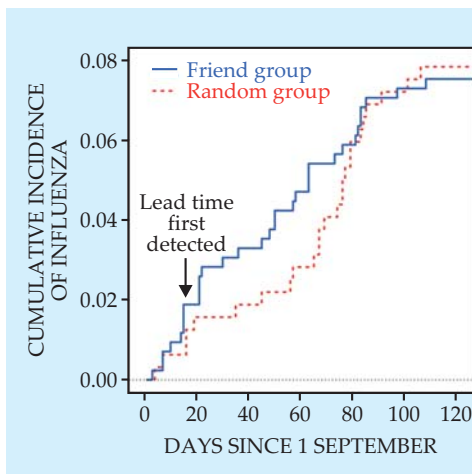
Knowledge of whether a disease epidemic is unfolding in a community is crucial for public health officials and policymakers. Models suggest that vaccinating even a third of the population against influenza in a metropolis like New York City or Chicago can save lives and shorten the epidemic's course—but only if implemented early enough. Unfortunately, current methods to monitor flu epidemics rely on contemporaneous data from random people seeking outpatient care, information that lags behind the course of the epidemic by a week or more.

Social networks, such as the network of real-life contacts in a city, are heterogeneous: Some members are more connected, or central, than others. Theorists know that the centralmost hubs, by virtue of their greater exposure, are most likely to catch and spread a contagion (see the article by Mark Newman in *PHYSICS TODAY*, November 2008, page 33). The question is, How to find them? Mapping the social network and monitoring its central members would be an ideal way to detect an emerging outbreak, but that's costly, time-consuming, and often impossible—especially in a large network.

A social-network phenomenon known as the friendship paradox—"your friends have more friends than you do"—offers a strategic path around the problem. To appreciate the phenomenon, described by sociologist Scott Feld in 1991, consider a group of randomly chosen people, each asked to name a

friend. More extroverts are likely to be named than loners, and the nominated friends will have, on average, more social ties than the nominators.¹ How many more depends on the variance in distribution of ties. Mathematical modeling by theorist Reuven Cohen of Israel's Bar-Ilan University and his colleagues in 2003 bore out the potential utility of the idea. According to their simulations of computer and population networks, given a million randomly chosen nodes (computers or people), only a small fraction of random "acquaintances" of those nodes actually require immunization to arrest an unfolding computer virus or disease epidemic, compared to a large fraction needed in completely random immunization.²

Last year, as the 2009 flu season approached, physician and sociologist Nicholas Christakis of Harvard University and political scientist James Fowler of the University of California, San Diego, realized they could experimentally test the paradox as a basis for early detection.³ In October 2009, after the H1N1 epidemic had emerged but before vaccines were available, they contacted 744 Harvard undergraduates: 319 randomly chosen students and 425 friends they nominated. By monitoring the two groups and consulting records from the campus health center dating back to 1 September, Christakis and Fowler found that the friend group tended to get the flu well before the random group, a trend first discernable about 46 days prior to the epidemic's peak (see the figure).

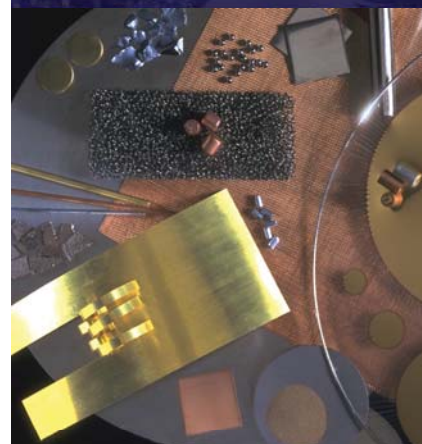


Differences in flu contagion between two groups, one composed of randomly selected Harvard University undergraduates and another composed of friends they nominated. Only 8% of the 744 students contracted the flu in 2009. Medical records show that members of the friend group tended to catch it earlier than the random group, as expected based on their greater average number of social ties in the population at large. A divergence of the curves is first detected at day 16. (Adapted from ref. 3.)

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The power of the approach, Christakis points out, is that in the event of an outbreak, the behavior of a small subgroup of the population presages the evolution in the much larger, and essentially unobservable, global network—without requiring details of anyone’s actual social ties. “We’re not claiming that people necessarily got the flu from the friends they nominated, nor that the local network maps the path along which the pathogen flows,” he says. “A ‘friend’ is just a proxy for an actual location in the network.” Armed with an advance warning from the health data about friends—or even friends of friends

for a yet more central set of nodes—health officials could then decide how best to forestall an epidemic.

Ideally, Christakis and Fowler note, groups should be selected before data are collected to avoid any hidden bias creeping into the data. Thanks to the proliferation of internet- and GPS-equipped mobile phones and social networking sites like Facebook, researchers can, at least in principle, quickly access staggering amounts of information in real time: where people are; with whom they interact; and what they like, buy, and blog about.

As people increasingly reveal them-

selves online and computational power grows to better handle the volume, researchers may gain insight into spreading processes in networks and how to anticipate their effects. In 2009 the H1N1 virus infected over 50 million Americans. There are now more than 150 million active Facebook users in the US.

Mark Wilson

References

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2. R. Cohen, S. Havlin, D. ben-Avraham, *Phys. Rev. Lett.* **91**, 247901 (2003).
3. N. A. Christakis, J. H. Fowler, *PLoS One* **5**, e12948 (2010).

Relativistic effects seen at everyday distances and speeds

Recent results highlight the precision reached by the latest optical clocks.

In George Gamow’s popular account of special relativity, his title character, Mr. Tompkins, dreams of a “Wonderland” in which passing bicyclists appear flattened by length contraction. Gamow achieved the effect in his fiction by setting the speed of light at a mere 30 miles per hour. Recently, researchers at NIST in Boulder, Colorado, also made relativity seem more commonplace, but not by resorting to a literary artifice. Instead, they used accurate clocks to measure the much smaller but very real relativistic effects that occur at everyday time and distance scales.

The NIST team has developed the most precise optical clocks in the world, based on the optical frequency of an electron transition in a single aluminum ion trapped nearly at rest (see the article by James C. Bergquist, Steven R. Jefferts, and David J. Wineland in *PHYSICS TODAY*, March 2001, page 37). In the recent experiment, the clocks could detect the minuscule relativistic effects that arise when the ion in one clock oscillates with an average speed of just 10 meters per second (about 22 mi/hr) relative to the stationary ion in a second clock, or when the elevation of one clock changes by as little as 33 cm.¹

The first of those effects is the equivalent of special relativity’s twin paradox. The oscillating ion plays the role of the traveler, whose clock runs more slowly than that of its look-alike at home. The second effect is the gravitational frequency shift experienced by clocks at different points in a gravitational potential.

The experiment is an excellent demonstration of the high performance

reached by NIST’s optical clocks, states Christophe Salomon of the École Normale Supérieure in Paris. The more accurate of the two clocks used in the experiment was unveiled last February² and has a systematic frequency uncertainty of 8.6×10^{-18} . By contrast, the current SI standard for time is a cesium-atom fountain clock, operating at microwave frequencies, with an accuracy on the order of 10^{-16} .

The NIST group is certainly not claiming to have made the most precise

test of relativity; many other techniques at various scales have put the theory through its paces. James Chin-Wen Chou, lead author on the new NIST paper, points out that among laboratory measurements, Mössbauer spectroscopy and atom interferometry have greater sensitivities to gravitational effects than atomic clocks, although the two clocks have the distinction that they can be located in separate laboratories. Holger Müller of the University of California, Berkeley, finds a philosophical

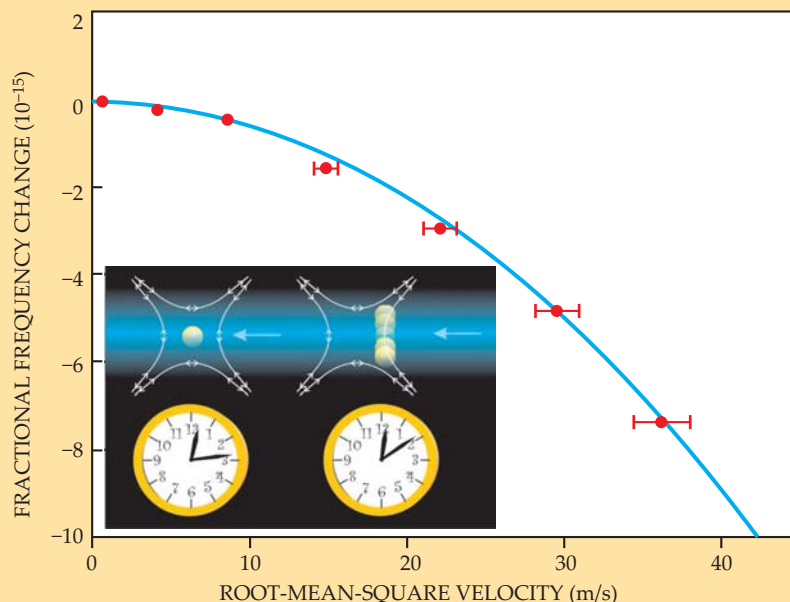


Figure 1. Time dilation is measured by comparing the frequencies of two ion clocks. In the left-hand clock of the inset, the ion remains stationary at the center of a trap. In the other, the displaced ion executes harmonic oscillations. The larger the root-mean-square velocity of the second ion, the greater is the frequency difference between the clocks. The blue curve is the theoretical prediction. (Adapted from ref. 1.)