How important is long-distance travel in the spread of epidemics?

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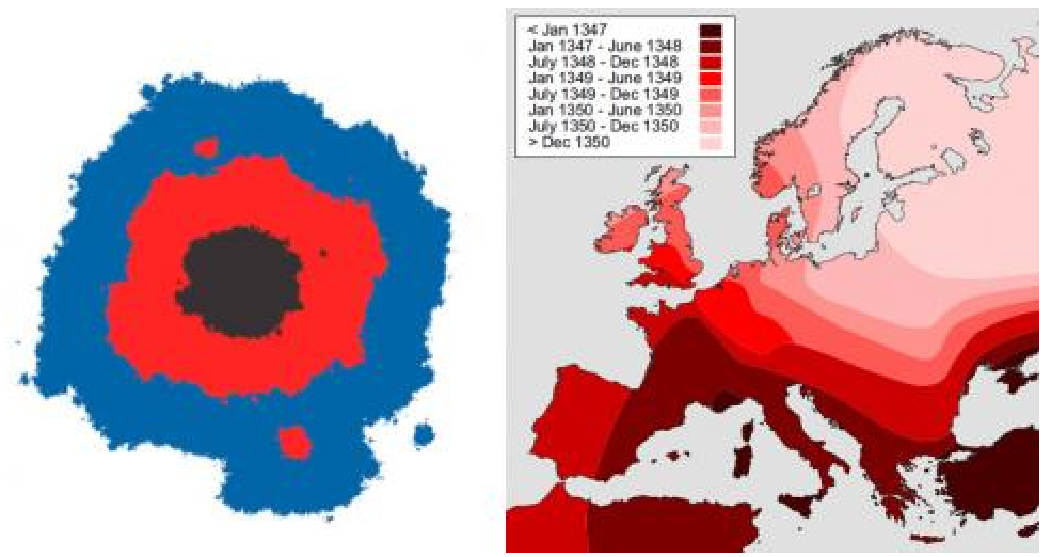

When long-distance travel is rare, epidemics spread like a slow, rippling wave, as demonstrated by the simulation (left) and the actual historical spread of the black death during the Middle Ages. Credit: Oskar Hallatschek and D. Sherman and J. Salisbury

The current Ebola outbreak shows how quickly diseases can spread with global jet travel. Yet knowing how to predict the spread of these epidemics is still uncertain, because the complicated models used are not fully understood, says a UC Berkeley biophysicist.

Using a very simple model of disease spread, Oskar Hallatschek, assistant professor of physics, proved that one common assumption is actually wrong. Most models have taken for granted that if disease vectors, such as humans, have any chance of "jumping" outside the initial outbreak area – by plane or train, for example – the outbreak quickly metastasizes into an epidemic.

Hallatschek and co-author Daniel Fisher of Stanford University found instead that if the chance of long-distance dispersal is low enough, the disease spreads quite slowly, like a wave rippling out from the initial outbreak. This type of spread was common centuries ago when humans rarely traveled. The Black Death spread through 14th-century Europe as a wave, for example.

But if the chance of jumping is above a threshold level – which is often the situation today with frequent air travel –the diseases can generate enough satellite outbreaks to spread like wildfire. And the greater the chance that people can hop around the globe, the faster the spread.

"With our simple model, we clearly show that one of the key factors that controls the spread of infection is how common long-range jumps are in the dispersal of a disease," said Hallatschek, who is the William H. McAdams Chair in physics and a member of the UC Berkeley arm of the California Institute for Quantitative Biosciences (QB3). "And what matters most are the rare cases of extremely long jumps, the individuals who take plane trips to distant places and potentially spread the disease."

This new understanding of a simple computer model of disease spread will help epidemiologists understand the more complex models now used to predict the spread of epidemics, he said, but also help scientists understand the spread of cancer metastases, genetic mutations in animal or human populations, invasive species, wildfires and even rumors.

The paper appears in this week's online early edition of the journal *Proceedings of the National Academy of Sciences*.

Epidemic spread

Hallatschek typically studies in a Petri dish how new mutations spread in colonies of microbes, activity that he models mathematically to understand how evolution fixes new traits in a population. When looking at simple theories of such "epidemic" spread, however, he was surprised to discover that no one knew the answer to a simple question: How does the long-distance dispersal of individuals during an outbreak affect the spread?

Simulations show that if the chance of individuals traveling away from the center of an outbreak drops off exponentially with distance – for example, if the chance of distant travel drops by half every 10 miles – the disease spreads as a relatively slow wave.

Simulations also suggested that a slower "power-law" drop off – for example, if the chance of distant travel drops by half every time the distance is doubled – would let the disease get quickly out of control."

"We were shocked to see that this had not been demonstrated, and saw a chance to prove something really fundamental," Hallatschek said.

The “Where’s George?” project tracked dollar bills around the world, providing data on human travel that can be important in understanding epidemic spread.

The simple model he used was stripped of real-world complexity, but contained the crucial ingredients needed to predict evolutionary spread and, more importantly, could be captured by a mathematical formula. Hallatschek discovered three types of epidemic situations involving power-law distributions.

In cases where long-range jumps are very rare, epidemics spread in a slow wave, typified by the Black Death. The invasive cane toad also spread in a slow wave after being introduced to Australia in the 1930s. When long-range jumps are common, the disease spreads very rapidly, as in 2002-2003 with SARS (severe acute respiratory syndrome), which was spread around the world by air travelers. An intermediate situation produces satellite outbreaks, but spreads far more slowly than SARS-like cases.

Hallatschek said that previous studies failed to take into account the randomness of jumps, which led people to think that any long-range jump would lead to new outbreaks and rapid spread. But if long-range jumps are extremely rare, distant outbreaks tend to be overtaken by the slow, wavelike spread of the initial outbreak before they can contribute much to the overall epidemic.

He noted that two recent studies of human dispersal – the "Where's George?" dollar bill tracking study and a 2008 cellphone-user mobility study – suggest that in the real world, humans disperse according to a power-law distribution over distances of up to hundreds of kilometers and exponentially over even longer distances.

In the future, he plans to make his model more and more realistic, first by incorporating networks to mimic the real world where people do not jump randomly, but must travel through airport hubs or train stations. Hallatschek also hopes to test his model by using data on the evolving genome sequences of pathogens as they spread, which provide one measure of where and when satellite outbreaks occur.

More information: "Acceleration of evolutionary spread by long-range dispersal." *PNAS* 2014 ; published ahead of print November 3, 2014, DOI: 10.1073/pnas.1404663111

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