Abstractions

FIRST AUTHOR
Generally, host density is thought to control the spread of infectious diseases — transmission cannot be sustained below a certain density or 'abundance threshold'. Stephen Davis, a postdoc at the University of Utrecht in the Netherlands, and his colleagues combined archived records of plague-carrying great gerbils (*Rhombomys opimus*) in Kazakhstan with satellite imagery of gerbil burrows. They applied percolation theory — typically used to model liquid flows in porous media — to show that both the distance and amount of contact between hosts can also predict disease outbreaks (see page 634). Davis suggests that percolation theory might provide an alternative framework for disease transmission, especially in wildlife.

Where did you start?
Plague-monitoring programmes were put in place in Kazakhstan in the 1940s, and ran until shortly after the 1991 collapse of the Soviet Union, when they could no longer be sustained. The European Union then helped to salvage and digitize these remarkable data. Abundance thresholds are frequently used by theorists, but our previous analysis of the data showed that plague in gerbils is a rare empirical example of such a threshold that reliably predicts outbreaks of disease. I wanted to know what biological mechanisms created the abundance threshold.

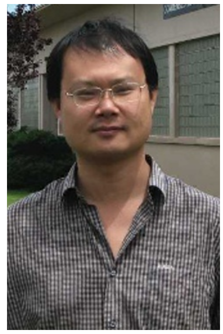
When did you realize percolation theory might work?
I initially applied the usual assumptions about host contacts being random, but it was like pushing a square block into a circular hole. Co-author Pieter Trapman introduced me to percolation theory and co-author Herwig Leirs asked if I had seen Google Earth. This allowed us to identify vast gerbil burrow systems in Kazakhstan. We then had data on three spatial scales — the distances fleas and gerbils move, disease monitoring over a long time period, and the burrow landscape — which is rare. Once we had put all of these data into a model, we found that a percolation threshold — an estimate of disease spread based on long-range connectivity of gerbil populations — emerged immediately.

Will percolation theory supercede the traditional approach?
No, but it's a shift in perspective. It depends on how hosts interact. Humans mix freely, but prey animals such as gerbils can't wander far from their burrows. If you look at host movements in the context of the landscape they inhabit, you can sense whether percolation might be relevant. That it is relevant to plague is surprising, because for a vector-borne disease in a vertebrate host to face such low mobility is unexpected. ■

MAKING THE PAPER

David Pines & Yi-feng Yang

Calibrating temperature and heavy-electron behaviour.



David Pines (left) and Yi-feng Yang.

A young physicist's exchange between two groups, one theoretical and one experimental, was a crucial facet of work that has shed new light on the behaviour of a group of superconducting materials, the heavy-electron compounds. Superconductivity is a valuable property that describes the phenomenon of having no electrical resistance, without which electrons — and so electric current — can flow freely within a material for extensive time periods without any energy being lost as heat. The problem is that all known superconductors only exhibit this behaviour at very low temperatures, which makes them impractical for many potential applications.

Heavy-electron materials — such as alloys containing cerium and ytterbium — display unusual, temperature-dependent behaviour that results from the interaction between electron spins of atoms on a chemically ordered lattice. As the temperature drops, the electrons first gain mass, and then, just above absolute zero, become magnetic and/or superconducting. David Pines, a theoretical physicist at the University of California, Davis, his postdoctoral fellow Yi-feng Yang, currently a visiting scientist at Los Alamos National Laboratory in New Mexico, and their co-authors have discovered a way to calculate the temperature scale that governs the emergence of heavy-electron behaviour.

"Determining this scale is important because it is the first step towards understanding the fundamental physics behind this behaviour," says Yang. He and Pines had shown previously that, for these materials, there is a temperature, T^*, above which the lattice of localized electrons behave individually and below which the electrons behave collectively. Now, they and their colleagues have come up with a simple equation for calculating T^* (see page 611). Because T^* sets the scale for superconductivity in these materials, this breakthrough may one day help with the design of new superconducting materials that function at higher, more practical temperatures.

Their equation applies to a number of heavy-electron materials with very different low-temperature properties. Pines credits the breakthrough to Yang's ability to work in the experimental as well as the theoretical sphere. An Institute for Complex Adaptive Matter (ICAM) fellowship provided him with the funds to travel between Pines's lab and one of the world's top experimental teams for heavy-electron materials — Joe Thompson's group at Los Alamos.

Yang admits that jumping into the middle of a bunch of experimental physicists was difficult and, at times, frustrating, but he managed to climb the steep learning curve. He examined more than 30 years' worth of experimental data on the heavy-electron materials before attempting to come up with an equation that would describe their behaviours at low temperatures. And, with the help of daily conversations and observations among the experimentalists, he eventually came to the solution for T^*.

"It is so easy for a young, gifted theorist to get caught up in trying to invent new mathematical models without having a sense of whether these relate to experiments," says Pines. "Yi-feng began by thinking about a phenomenological description of what was going on, rather than rushing to what would have almost certainly proved to be an inadequate calculation."

> "Forget about equations for a minute and just try to describe a picture."
> — Yi-feng Yang

The experimentalists, Yang says, provided a new perspective. "At times I used to think about everything in a very theoretical way and derive some equations," he says. "But that's not how they think about it. Experimental physicists have a picture in their head of what is going on and they do experiments to try to add to that picture. I learned a lot from this way of thinking — forget about equations for a minute and just try to describe a picture."

Pines says that this marriage of theory and experiment is the only way to make progress on frontier problems such as emerging behaviours in new classes of materials. An experimentalist might make an off-hand comment such as, "Oh yeah, there is that funny result I saw that didn't quite fit what we were expecting," he says, and that might be the signature of an emerging behaviour that a theorist can seize upon.

Both feel that Yang has found his calling in bridging experimental and theoretical work on the heavy-electron compounds — a class of materials whose mysterious properties have put them in the spotlight of superconductor research. In the drive to ultimately design superconducting materials that work near room temperature, says Pines, "the heavy-electron materials come front and centre". ■

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