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A new angle on complex dynamics

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ing the diffusive-scattering regime to longer phonon wavelengths. But even perfectly diffusive scattering at all wavelengths wouldn't fully explain the precipitous drop. Phonon spectrometry could provide a more rigorous way to probe and quantify the behavior.

The Cornell team's approach may also aid the development of nascent applications such as phononic logic circuits and frequency-selective transport via phonon echo chambers. "Right now, one of my grad students is making nanoholes in the mesas and trying to come up with spacings that would give rise to phononic crystal effects," says Robinson. "Now that we can fabricate a microscale phonon spectrometer, we can explore questions that were previously inaccessible."

Ashley G. Smart

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A new angle on complex dynamics

Analyzing changes in direction in stochastic trajectories can offer valuable insights.

Random walks arise in many areas of physics and other sciences. They don't all look the same. A particle moving freely behaves differently from a particle in a static potential, which behaves differently from a particle that's being actively transported, and so on. In biological systems, from atoms in a protein to birds in a flock, the complex interactions between components give rise to an especially rich variety of possible dynamics. The usual way to characterize random-walk trajectories, such as the one shown in the figure, is by looking at the displacement vectors $\mathbf{V}(t;\Delta)$ describing the particle's motion from time t to time $t+\Delta$. One particular favorite measure is the mean-square displacement, the average of $V^2(t;\Delta)$ over all t for a particular Δ. In simple Brownian motion, in which each time step is completely uncorrelated with all the others, the mean-square displacement grows linearly with Δ; a different functional form is a sign of anomalous dynamics.

Now Stanislav Burov, Aaron Dinner, and colleagues at the University of Chicago have shown that by analyzing the angles $\theta(t;\Delta)$ between successive displacement vectors, they can uncover complex dynamics that are otherwise obscured.[1] Because an angle is a function of three points rather than two, the distribution of $\theta(t;\Delta)$ for a given Δ can be a sensitive measure of whether a trajectory's direction is influenced by a retained "memory" of the system's past configurations.

Burov developed the idea while analyzing experimental data on the transport of insulin in mouse pancreatic cells.[2] The cells synthesize insulin molecules, package them into "granules" some 300 nm in diameter, and then shuttle the granules close to the cell surface so they can be rapidly released when needed. The mechanism governing granule transport may also account for the two-phase secretion of insulin in response to a glucose spike—a sharp, fast release followed by a sustained, slower one—and thus for the disruption in that secretion pattern associated with type-2 diabetes.

The Chicago researchers were among the first to look at insulin-granule dynamics at the level of single trajectories. Unsurprisingly, it's not simple Brownian motion. When they tried to classify it as one of the known types of non-Brownian motion, different statistical tests on the $\mathbf{V}(t;\Delta)$ data gave conflicting results.[2]

Turning from displacements to angles, the researchers found that distributions of $\theta(t;\Delta)$ peaked at $\theta = 0$. That is, the granules showed a preference for continuing to move in the same direction, a signature of active transport. But they also found a second set of peaks at $\theta = \pi$, indicating a tendency for the granules to reverse direction. "We were amazed," recalls Dinner. "We hadn't appreciated that the granules were making reversals, despite our extensive analysis of the mean-square displacement. We're just starting to understand how the cells' underlying filament network shapes the granule dynamics."

The researchers have since applied their method to several other simulated and experimental systems. They've found examples of peaks in the θ distribution that grow or shrink with increasing Δ (indicating the gain or loss of correlations on a particular time scale) or remain unchanged (indicating self-similarity). They've also found that systems with similar-looking mean-square displacements can yield very different patterns in θ. The method is still in its infancy, and the precise relationship between θ distributions and physical dynamics is still murky. But as the theory matures, Dinner and colleagues anticipate that it could find application in a variety of disciplines, from polymer dynamics to information transfer in networks.

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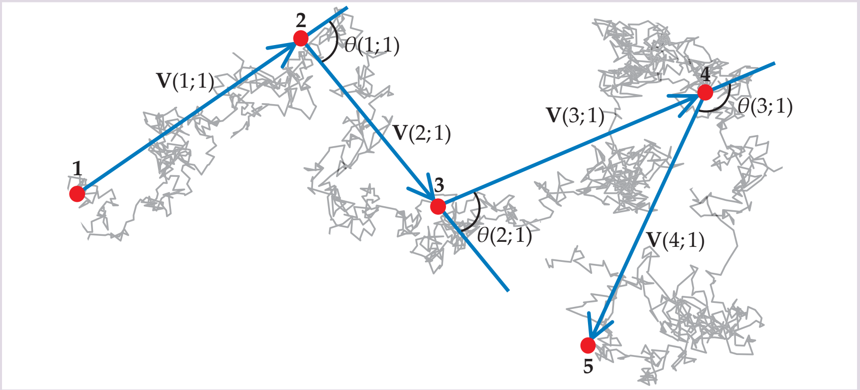

Random-walk trajectories, such as the one shown here in gray, are typically analyzed by looking at the displacement vectors $\mathbf{V}(t;\Delta)$; blue arrows show displacement vectors for several values of t and one value of Δ. The angles $\theta(t;\Delta)$ between successive displacement vectors can reveal complex dynamics that the vectors themselves do not. (Adapted from ref. 1.)