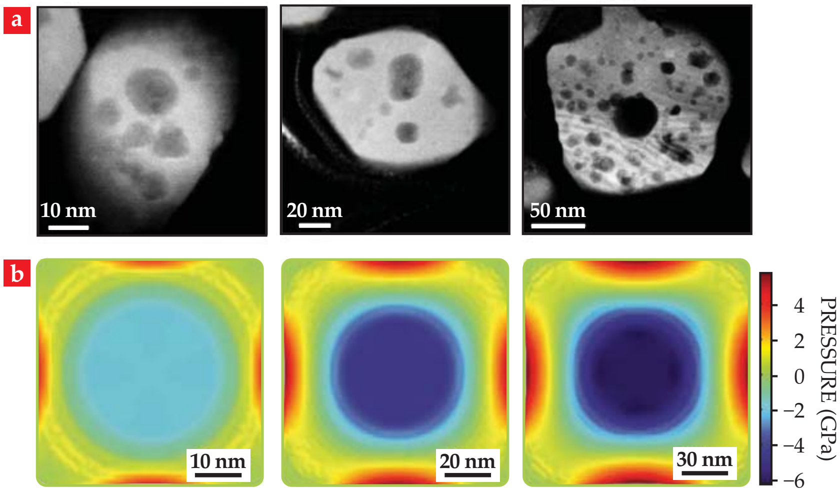

Figure 2. Lead titanate nanowires with diameters of 50 nm, 100 nm, and 150 nm. **(a)** Experimental cross-sectional images show the spherical nanopores that take up some of the volume difference between the PX phase and the perovskite phase. **(b)** Numerical simulations show that as the wire diameter increases, so does the magnitude of the negative pressure at the wire's center. (Adapted from ref. 1.)

figure 1b—are numerous and abundant, their applications are diverse, and many have low-density metastable phases similar to the PX structure. Setter speculates that many nonperovskite materials could also be made to undergo density-increasing transformations that start at the surface and proceed inward—and that extending the negative-pressure technique to different materials could enhance useful properties in ways theorists haven't yet explored.

Indeed, a similar method is already widely used to make tempered glass. Rapidly cooling a piece of hot glass causes it to contract to produce a material whose surface is under compression and whose core is under tension. Those stresses are responsible for tempered glass's advantageous mechanical properties, including fracture toughness and shattering behavior.

Although Setter, Wang, and company's individual $PbTiO_3$ nanowires are tiny, the total quantity of material can readily be upscaled. The PX-phase wires are easy to make, and the conversion to perovskite is as simple as heating the wires in air. "I foresee bulk applications" for negative-pressure nanomaterials, says Setter, "in powder form, as paints, or as composites."

Johanna Miller

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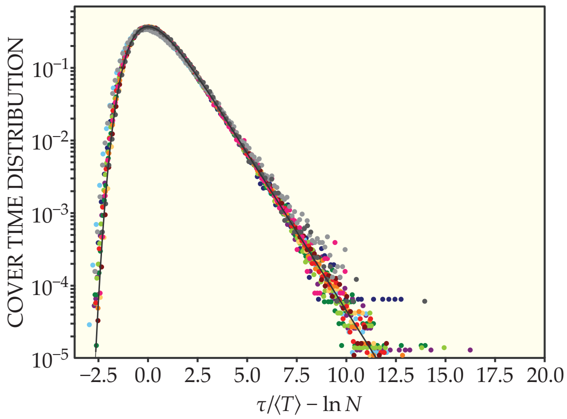
The universal statistics of random searches

The time it takes a random walker to find all the targets in a given domain can be determined from the average time it takes to find just one of them.

How efficient can an exhaustive search be? Whether the goal is to locate every mushroom in a forest, say, or specific sequences on a DNA strand, the cover time τ—defined as the time it takes for a random walk to find all the targets in a spatial network—can quantifiably answer that question. But despite τ's relevance to a broad range of situations, from animals foraging for food to diseases spreading through a city, analytical results have been scarce and mostly limited to regular random walks—those involving moves between nearest neighbors in Euclidean geometry.

Not all random trajectories look the same, and in more complex strategies, the random walker's movement among neighbors differs from diffusive



The cover time τ is the time it takes to randomly find all the targets N in a given domain. The theoretical expression for its probability distribution (the black curve) is given by $P(x) = \exp(-x - \exp^{-x})$, where $x \equiv \tau/\langle T\rangle - \ln N$ and $\langle T\rangle$ is the mean first-passage time to a given target site averaged over all starting sites. Provided N is large, the distribution is universally applicable to numerous complex search strategies in one, two, and three dimensions on a lattice. Monte Carlo simulations of the cover times, plotted with different colors for different strategies and dimensions, fall along the same distribution.

Brownian motion: It can be "persistent," for instance, weighted toward a particular direction that depends on a previous step; be "intermittent," stepping between nearest neighbors at one rate and leapfrogging over them at another rate to resume the search elsewhere; or take so-called Lévy flights, which jump from one region to another with step lengths that follow a power-law distribution. (See the article by Joseph Klafter, Michael Shlesinger, and Gert Zumofen, PHYSICS TODAY, February 1996, page 33.)

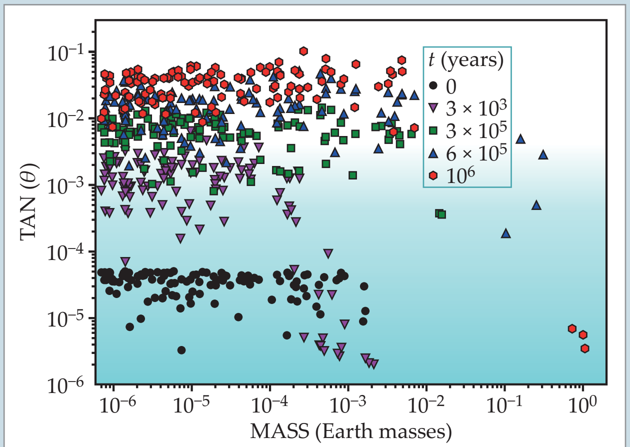
For those and other complex strategies, researchers have focused almost entirely on the time required to reach a single target—the first-passage time T—and have set aside the much harder problem of determining τ. Now CNRS theorists Marie Chupeau, Olivier Bénichou, and Raphaël Voituriez have linked the two quantities and analytically derived the probability distribution of τ for several different complex random-walk processes on a finite lattice network.[1]

After first writing an expression for τ in terms of a sum of the individual times needed to find each new target among the unfound ones on the lattice, the theorists made a bold hypothesis: Although those individual times depend on the entire random trajectory the walker has taken—and are thus

physics update

These items, with supplementary material, first appeared at http://www.physicstoday.org.

Building a solar system pebble by pebble. Broadly speaking, planets form in a gaseous nebula around a star as dusty matter accumulates into ever larger associations. But implementing that evolution in a detailed simulation has proved challenging. In many models, the nebula does not endure long enough for the cores of giant planets to agglomerate. Other models suggest that "pebbles," perhaps a millimeter to a meter across, are slowed by frictional interactions with the nebular gas and rapidly coalesce into 100- to 1000-km-sized planetary embryos that grow to planet size by accreting remaining pebbles. That mechanism, however, seems too effective; simulations typically produce hundreds of Earth-sized planets in a solar system. Now Harold Levison of the Southwest Research Institute and his colleagues have added a twist to the simulations—a nonzero formation time for pebbles—and obtained a realistic number of rocky and gas-giant planets. As nebular dust coalesces into pebbles, they find, the largest of the massive planetary embryos present at the beginning of the simulation gravitationally scatter their smaller siblings out of the protoplanetary disk. Thus most embryos are starved of the material needed for further growth; only a few become large enough to form rocky planets or gas-giant cores during the 1 million- to 10 million-year life of the disk. The figure summarizes a representative simulation. The angle θ denotes the inclination of an embryo orbit with respect to the protoplanetary disk, whose angular width is indicated by the blue region. After just 3000 years (purple triangles), a substantial fraction of the embryos initially present (black dots) has already been ejected. By the time the simulation terminates (red hexagons), less than a handful of embryos have grown to Earth size. (H. F. Levison, K. A. Kretke, M. J. Duncan, *Nature* **524**, 322, 2015.) —SKB



The Sun's tilted axes. As hikers and other navigators know, Earth's magnetic axis is tilted with respect to its rotation axis. Such misalignment had not been expected in the Sun—but now it's been seen. NASA's *Solar Dynamics Observatory* (*SDO*) has been trained on the Sun for half of the current 11-year cycle of solar activity. Using *SDO*'s Helioseismic and Magnetic Imager, Adur Pastor Yabar of the Institute of Astrophysics of the Canary Islands and his colleagues created daily maps of the line-of-sight strength and polarity of the Sun's magnetic field for each of the mission's first 1700 days. The Sun's rotation period varies with latitude: It's 25.5 days at the equator and 34.4 days at the poles. To look for variations *not* associated with differential rotation, Pastor Yabar and his colleagues averaged each map over all longitudes in 1-degree-wide latitudinal belts. When the researchers Fourier-transformed the entire sequence of binned maps, they discovered that a more-or-less monthly oscillation showed up at every latitude on every day. Random sprouting of active regions that rotate in and out of view could conceivably account for the oscillation, but when the researchers excluded active regions, the oscillation persisted. Their latitudinal belts did not sample the same parts of the Sun, as they had assumed, but wobbled up and down over the solar disk—hence the oscillation. Based on that and other lines of evidence, Pastor Yabar and his colleagues concluded that the Sun's magnetic and rotational axes must correlated—they can be treated as independent variables, provided the number of targets N is large. Armed with that hypothesis, which they later checked numerically, the CNRS researchers exploited the fact that the distribution of the "global" first-passage time $\langle T\rangle$—that is, the mean value of T averaged over all starting positions—is an exponential. That, in turn, led them to an expression for τ's probability distribution, plotted on page 18.

Remarkably, Chupeau and her colleagues found that when τ is rescaled in terms of the global first-passage time, its probability distribution becomes universally applicable to any of the several complex search strategies the theorists considered. That is, although τ itself is dependent on the dimensionality and connectivity of the network and the specific rules a random walker follows to search it, the probability distribution for $\tau/\langle T\rangle$ is completely insensitive to them: All the data points the researchers obtained by numerically simulating the different strategies fall on the same curve.

After deriving the distribution, the team recognized its resemblance to the so-called Gumbel distribution, used to model extreme-value problems such as the likelihood of an electric current fluctuating above some critical threshold or the chances of a river reaching flood stage. That the distribution of cover times should follow the same statistics isn't entirely unexpected since τ, by definition, is the time it takes to find *all* the targets in a given domain and is thus the largest of the arrival times at each target. The bigger surprise is that short-time dynamics, in which correlations between time and trajectory are important, become irrelevant. So much greater is the time needed to find the last few targets in the limit of a large number of them that the correlations are apparently negligible to the statistics.

That's not to say that one search strategy isn't more efficient or better suited for a particular problem than another. To determine the distribution, mean, most probable value, or variance of τ for a specific strategy, one needs only to reverse the scaling in the plotted distribution. What's more, thanks to that direct and robust connection between first-passage and cover times, the researchers found that if you optimize search parameters to minimize $\langle T\rangle$, you will have automatically also minimized τ. As Voituriez puts it, "One and the same strategy minimizes both times—an entirely unexpected result."

Mark Wilson

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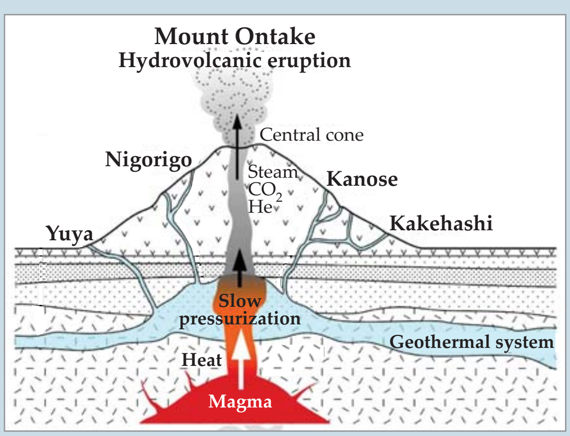
1. M. Chupeau, O. Bénichou, R. Voituriez, *Nat. Phys.* (in press), doi:10.1038/nphys3413.

be misaligned. Dynamo models that presume alignment will require modification. (A. Pastor Yabar, M. J. Martínez González, M. Collados, *Mon. Not. R. Astron. Soc.* **453**, L69, 2015.) —CD

A surprise eruption's decade-long buildup. On 27 September 2014 Mount Ontake in central Japan unexpectedly spewed an ash plume 7–10 km into the air and sent a deadly mix of hot gas and rock rushing down the south face of the mountain. The hydrovolcanic eruption, caused when rising magma heated groundwater into explosively expanding steam, killed more than 50 people. An international team of researchers led by Yuji Sano of the University of Tokyo now suggests that a warning sign may have been growing for years. The group had been periodically monitoring ratios of helium-3 to helium-4 in nearby hot springs since 1981. That ratio is a well-known signature of volcanic activity because changes in the relative abundance of ^{3}He, which originates in Earth's mantle, is often a telltale sign of changing magmatic activity. However, such a signature had never been observed before as a precursor to a hydrovolcanic eruption. At Mount Ontake, the ^{3}He/^{4}He ratio at Nigorigo, the spring closest to the volcano, steadily increased for 10 years prior to the eruption. At three springs farther afield—Yuya, Kanose, and Kakehashi—the ratio showed no significant change during the same period.



As illustrated in the figure, hydrodynamic models based on the group's data indicate that increased input of volatiles from the magma into the local geothermal system slowly caused pressure to build up in the volcano until it catastrophically erupted. Sano and his colleagues say the new findings can't be used to make short-term predictions, but they anticipate efforts like theirs could provide guidance on long-term risk management at Ontake and other volcanoes. (Y. Sano et al., *Sci. Rep.* **5**, 13069, 2015.) —SC

Quantifying scientific collaboration. Research collaboration is increasingly common in today's scientific world. The practice grows out of colocation, mentoring, complementarity, and other factors. Much of the "science of science" research has focused on collaboration patterns that emerge from data aggregated over individuals, time, and disciplines. Alexander Petersen of the IMT Institute for Advanced Studies in Lucca, Italy, has now analyzed collaborations, as manifested in publication and citation records, with a focus on the individual researcher. He considered the career data of 473 scientists, 193 from biology and 280 from physics. For a given researcher, Petersen quantified the tie to each coauthor based on duration (the time between first and last coauthored papers), strength (the number of coauthored papers), and impact (the number of citations to coauthored papers). The evolution of each researcher's network reflects specific career events such as relocations, discoveries, and major prizes. Petersen found that in both biology and physics, collaboration networks are dominated by weak, short-lived connections, especially late in one's career. But his analysis also revealed the existence of "super ties": extremely strong, long-duration collaborations that lead to above-average productivity and citation rates. Such super ties—the research analogue of a life partner—are thus a major factor in career development. Biologists tend to have more super ties than do physicists, yet the frequency of super ties for both groups is surprisingly high: typically one for every 25 coauthors, independent of a researcher's prestige or overall productivity. (A. M. Petersen, *Proc. Natl. Acad. Sci. USA* **112**, E4671, 2015.) —RJF