

of both are low, wide lobes emerge instead.

To explore a pattern common to 2D gardens—and discernable in some 3D ones—De Wit and her colleagues analyzed the growth kinetics of 173 curly-shaped precipitates they observed in several experiments (marked  $S_1$  in figure 1). The shapes, shown more clearly in the magnified view of  $S_3$  in figure 2, were pervasive throughout a wide range of intermediate concentrations. And all of

the curls conformed to the mathematics of a logarithmic spiral—the logarithmic dependence of angle on radius—the same structure found in natural systems such as seashells, snail shells, and the horns of animals. In the case of their experiments, De Wit says, “what matters is to have a solid that is pushed, breaks, and starts to rotate when material is added in a self-similar way at the end of a propagating tip.”

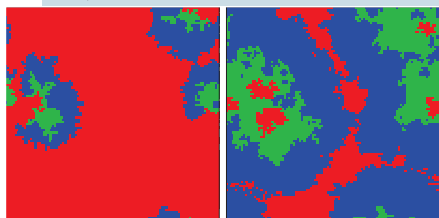
Cartwright adds that so generic a

model—independent of chemical details—is merely a first step to quantifying how the 2D system behaves. “We’re hoping to model other features, such as the filaments, which are reminiscent of the stalks, or tubes, in 3D gardens, to further constrain the growth mechanism,” he says. A detailed and quantitative 2D model would surely provide some insight and predictive power over the behavior of 3D gardens and such natural formations as deep-ocean hy-

## physics update

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

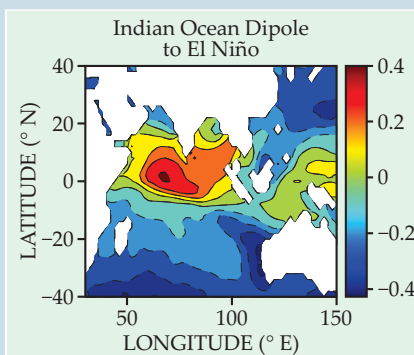
**The cost and benefit of deception.** Imagine the police arrest you and a colleague for some crime and offer individual deals if you will betray each other. If only one of you defects, that person goes free while the other, the cooperator, receives three years in prison. Mutual defection gets both of you a two-year sentence, and mutual cooperation results in a one-year sentence. That game theory scenario is called the prisoner’s dilemma. Versions of it, often involving many players who adapt their strategies as they repeatedly play the game, have been used to study how cooperative behavior might evolve in a population of competing individuals. Now Attila Szolnoki of the Hungarian Academy of Sciences and Matjaž Perc of the University of Maribor in Slovenia and King Abdulaziz University in Saudi Arabia have introduced deception to the game. They ran Monte Carlo simulations with up to  $3.6 \times 10^7$  players interacting on a square lattice. In addition to defectors,



the simulations included conditional cooperators who defect if they detect a defecting opponent, and deceptive defectors who always avoid detection, though at a cost. After playing against its four neighbors, a player could switch strategies depending on how well it did in comparison to the previous player; a randomly chosen neighbor then went next. The figure above shows snapshots from one simulation after 60 (left panel) and 100 (right panel) Monte Carlo steps; the population of cooperators (blue) grew at the expense of defectors (red), but in turn lost ground to deceptive defectors (green). The researchers found that such complex dynamics led to surprising evolutionary outcomes. For example, deception sometimes became more effective when its cost increased, and upping the likelihood of detection didn’t always promote cooperation. (A. Szolnoki, M. Perc, *New J. Phys.* **16**, 113003, 2014.)

—SC

**Quantitative causality.** Cause and correlation are two different notions that are often confused. When phenomena  $A$  and  $B$  are causally related, their time evolutions are correlated. But correlation does not imply causality—an external agent such as an alarm clock, for example, can cause the correlated waking of two sleepers; the two isolated wakings, however, are not causally related. When the dynamics governing  $A$  and  $B$  are known, an information-theoretic notion called



information flow rigorously determines the causal relations between  $A$  and  $B$ : If the information flow from  $A$  to  $B$  is zero,  $A$  has no effect on  $B$ ; otherwise,  $A$  does affect  $B$ . Now X. San Liang of the Nanjing University of Information Science and Technology in China has shown how to obtain the information flow, not from *a priori* known dynamics but from correlations in the time-series graphs that detail the evolutions of  $A$  and  $B$ . He applied his result to a problem of practical interest for climate scientists—the relation between El Niño and the Indian Ocean Dipole (IOD), an aperiodic oscillation in sea surface temperature. Liang used correlations between time series—of sea surface temperatures in the Indian Ocean and of an index, called Niño4, that measures the overall strength of El Niño—to calculate the information flow from the IOD to El Niño shown in the figure. For a large swath of the northern Indian Ocean, the sign of the information flow is positive, which, according to information theory, means the IOD causes El Niño to be less predictable. That unusual causal link, suggests Liang, may be the reason climate scientists only recently recognized an influence of the IOD on El Niño. (X. S. Liang, *Phys. Rev. E* **90**, 052150, 2014.)

—SKB

**Detecting shielded uranium in the field.** Security personnel use several methods to detect suspect materials such as explosives and dangerous chemicals (see *PHYSICS TODAY*, June 2014, page 62). But uranium—especially the highly enriched weapons-grade version—can be difficult to spot because it is easily shielded by a relatively small amount of lead, which absorbs the fissile material’s telltale emissions. However, neutrons directed at a suspect object can readily penetrate the lead shielding and produce enough fission neutrons and gamma rays to be detected. For field operations, small and light neutron sources are needed. Jennifer Ellsworth and a team of researchers at Lawrence Livermore National Laboratory (LLNL) have developed a suitcase-sized prototype neutron source that they say can be shrunk to a 5-kg, 20-W, lunchbox-sized device that could be easily transported to inspect a suspicious item. Central to the device is an array of 40 etched iridium tips (in the assembly at left in the figure). The 100-nm-radius tips concentrate the electric field from a com-

drothermal vents, rust tubes emanating from corroded iron or steel, and hollow, briny icicles under Arctic sea ice.

De Wit and her colleagues see another compelling application for their approach: building new complex materials. By turning to a catalog of patterns or phases like the one in figure 1, researchers may be able, De Wit speculates, to control the reaction well enough to produce the desired pattern and complexity. But that's a goal for the

long run. And it may involve other building blocks. A related class of self-assembling mineral aggregates known as silica biomorphs also exploits steep pH gradients like those found in chemical gardens—though using a different mechanism—to assemble leaf-like sheets, helical filaments, and “cauliflower” (see PHYSICS TODAY, March 2009, page 17).<sup>3</sup>

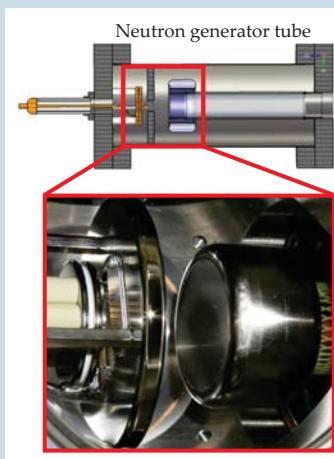
Possibilities abound. It's intriguing to imagine, for instance, a filament-rich

chemical garden, tailor-made using an appropriately tweaked recipe, operating as a microfluidic delivery system or catalytic filter.

Mark Wilson

## References

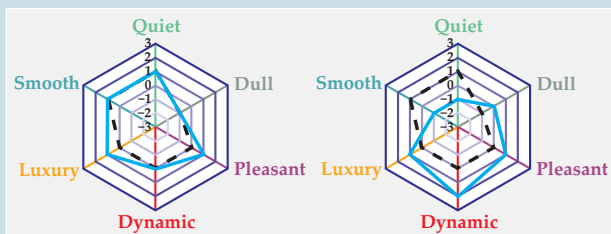
1. S. Thouvenel-Romans, O. Steinbock, *J. Am. Chem. Soc.* **125**, 4338 (2003).
2. F. Haudin et al., *Proc. Natl. Acad. Sci. USA* (in press), doi:10.1073/pnas.1409552111.
3. See also W. L. Noorduin et al., *Science* **340**, 832 (2013).



compact 10- to 20-kV power supply; the concentrated field rips apart and ionizes the molecular deuterium gas near the tips. Impinging on a tritiated-titanium target (at right) that is biased to  $-100$  kV, a pulsed  $D^+$  current of 120 nA in the prototype generates bursts of  $10^7$  14-MeV neutrons, a flux that is an order of magnitude higher than was previously available in field-ionization neutron sources. The team's proto-

type has produced  $D^+$  currents up to 500 nA while consuming less than 10 W. The LLNL team is bringing the size and weight down and the output up, which will allow neutron analysis to join portable x-ray devices in the field of nondestructive materials interrogation. (J. Ellsworth et al., *J. Appl. Phys.* **116**, 193301, 2014.) —SGB

**Sound design for electric vehicles.** The interior of an electric vehicle can sound eerily quiet without the noise of a combustion engine, yet also annoying due to unfamiliar, high-frequency sound components. Options for introducing virtual sounds are boundless, but as Soogab Lee and colleagues at Seoul National University show, psychoacoustics and musical harmonic theory can offer guidance. Both loudness and sharpness, which is related to the proportion of high-frequency components, can negatively affect pleasantness. To enhance the dynamic impression, the researchers wanted the sounds to correlate with speed. Harmonious



engine sounds, whose frequencies are in simple integer ratios, have been found to be more pleasant, so the Seoul team focused on tones harmonically related to the car interior's dominant high-frequency component during acceleration. The researchers had 27 volunteers evaluate five combinations of added tones (available online) by rating their overall im-

pression and then describing the sounds in terms of attribute pairs “pleasant–unpleasant,” “calm–dynamic,” “smooth–rough,” “loud–quiet,” “sharp–dull,” and “luxury–cheap.” As shown by the figure's blue lines, two of the five were rated higher for luxury and pleasantness than the base sound (dashed line) and were more preferred overall. For the combination rated on the left (the fourth audio sample), the original and added tones had the frequency ratio 5:3:1, reminiscent of a clarinet. The other (the third sample), with subharmonics that were three and four octaves below the original, was deemed rougher and louder but more dynamic. That combination was particularly favored by the dozen testers who like their cars “sporty.” (D. Y. Gwak et al., *J. Acoust. Soc. Am.* **136**, EL391, 2014.) —RJF

**Extragalactic Rydberg atoms.** The cold neutral medium (CNM) is one of the most enigmatic components of interstellar space. Conditions that prevail in the low-temperature, low-density CNM are such that carbon atoms are more likely to be ionized than the more abundant hydrogen atoms. And when those atoms recombine with ambient electrons, they can form fragile, high-quantum-number Rydberg states whose initial deexcitations entail the emission of



low-energy photons. Photons from those deexcitations have now been seen outside our galaxy for the first time. Leah Morabito of Leiden University in the Netherlands and her collaborators found them in the nearby star-forming galaxy M82; they used LOFAR, an array of about 20 000 radio dipole antennas centered in a field outside the Dutch village of Exloo. LOFAR can barely detect individual Rydberg transitions in M82. But by stacking the spectra of 22 transitions from quantum numbers 468–508 down to the next lowest state, Morabito and her colleagues obtained an 8.5-standard-deviation detection. For this proof-of-concept observation, only LOFAR's central 2-km core was used (see figure). Although the core couldn't resolve M82's structure, the stacked spectrum's profile suggests that the origin of the carbon absorption lies in the vicinity of the galaxy's star-forming nucleus. Future observations with the full array will pinpoint the carbon's location. The discovery of extragalactic Rydberg absorption opens a new window on the CNM, which LOFAR's more sensitive successor, the Square Kilometer Array, is poised to exploit when it debuts next decade. (L. K. Morabito et al., *Astrophys. J. Lett.* **795**, L33, 2014.) —CD