Fine-tuned collective behavior under acoustic stimulation

Emergence of an enslaved phononic bandgap in a non-equilibrium pseudo-crystal
Authors: Bachelard, N., Ropp, C., Dubios, M., Zhao, R. Wang Y., Zhang, X.
Nat. Mat. 16, 808 (2017)

Recommended with a Commentary by Jeremy England, Department of Physics, Massachusetts Institute of Technology

The traditional approach to building something useful starts with designing how its constituent parts must be arranged with respect to each other so that the whole assemblage accomplishes a desired goal. With a design in hand, the task before the builder then is to deliberately and carefully put each piece in place according to the plan. Increasingly, however, experimenters are exploring scenarios of self-assembly that operate according to a wholly different paradigm, in which the unfettered physical dynamics of individual particles can discover a target collective behavior without there ever being a blueprint for how the assemblage is supposed to look when it is done [1]. This paper provides an intriguing example of this new approach in the far-from-equilibrium regime.

Bachelard et al. use a 2 m long and 2.2 cm diameter acrylic tube filled with a viscous surfactant as a one-dimensional acoustic waveguide. Twelve plastic particles of millimeter dimensions sit in the meniscus of a viscous liquid at the bottom of the tube, which had sound supplied at one end from a computer speaker. They stimulate the particles using this acoustic source with a 3.9 kHz tone and read out the transmission spectrum of the medium by sending a frequency-chirped probe and detecting the result with a microphone at the other end of the waveguide. The system is therefore many-body enough to exhibit collective behavior (because of the particle degrees of freedom), non-linear (because of fluid dynamics and excluded volume of particles), nonequilibrium (because of the mechanical energy input from the acoustic field), and dissipative (because of the loss of energy through heat due to viscous drag).

Whatever the initial arrangement of particles, after a transient period of driving they are generally observed to settle into a non-periodic arrangement with respect to each other whose striking collective property is that it possesses a transmission bandgap whose position in the spectrum is entrained to the chosen frequency of the acoustic driving field. There is a high-dimensional space of possible many-body arrangements for twelve particles, but the reliable tendency in this system is for the dynamics to select and stabilize arrangements whose acoustic properties are finely tuned to the drive. This effect is reminiscent of a phenomenon demonstrated in simulations of self-rewiring spring networks [2], and may operate by a related mechanism: the resonant phenomenon allows the drive to deliver more energy into the system, which in turn enables the system to move and rearrange further. Stability may therefore arise because the finely-tuned states get less help from the drive in exiting their current configuration.

The number of particles and diversity of possible arrangements in the system considered here is still relatively small; clearly, with a higher-dimensional space of possible arrangements the acoustic transmission properties would have a great opportunity to bear a more specific imprint from a drive that was described by more than one parameter or frequency. The all-important question would be whether, as the number of particles and the freedom given to them to arrange in space both increase, the system maintains its tendency to settle into a fine-tuned attractor in the presence of a driving field or instead gets overwhelmed by the vastly greater internal entropy of uninteresting arrangements. Encouragingly, in this case the authors were able to use a computer simulation framework to reproduce the effect they observed experimentally. Such a computational approach may therefore prove to be an ideal way to investigate further whether more elaborate experiments in self-organized properties of nonequilibrium materials are likely to be interesting in this type of system.

References

[1] Nguyen, M. and Vaikuntanathan, S., "Design principles for driven self-assembly." *Proc. Natl. Acad. Sci.*, **113**, 14231 (2016).
[2] Kachman, T., Owen, J. and England, J. "Self-organized resonance during search of a diverse chemical space." *Phys. Rev. Lett.,* **119**, 038001 (2017).