Scientists lay out why some origami won't fold under pressure

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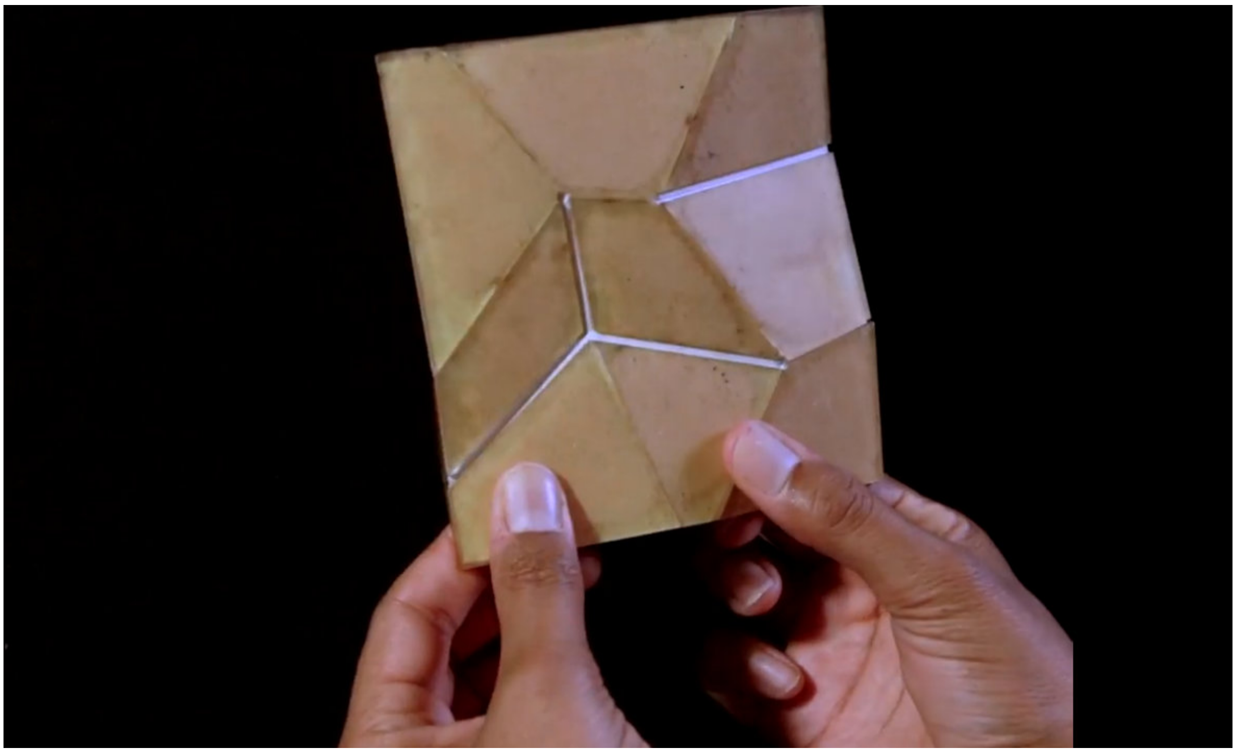

Scientists and engineers are fascinated by self-folding structures. Imagine the possibilities: heart stents that unfold in the right location or pop-up tents that assemble at the press of a button, as well as nanoscale versions for tiny machines. But sometimes these structures get stuck during the folding process, and scientists don't know why.

A new paper in *Physical Review X* by three University of Chicago scientists lays out a mathematical explanation—such sticking points are simply intrinsic.

"People thought you could engineer around it, but it really looks like there are fundamental limits," said graduate student Menachem Stern, the first author on the paper.

Structures designed to self-assemble often start out correctly, but then the folding peters out, leaving behind islands of properly folded parts. To explore why, the team created a set of mathematical models.

When designing structures that can fold themselves, whether paper origami or tiny nanomachines, scientists start by pre-creasing the folds they need. But this also creates a set of invisible "distractor" branches. The more pre-creases added, the more distractor branches form, and the origami is more and more likely to get stuck.

"No matter how clever the design, there are always many more ways to fold incorrectly and get stuck than to fold correctly," said Arvind Murugan, assistant professor in the James Franck Institute and coauthor on the paper. "We realized that this problem of having many more ways to do something incorrectly than correctly shows up in many other areas of science and mathematics, including the design of protein structures in biology and the design of Sudoku puzzles."

Using these connections, there are ways to mitigate the problem even if it is intrinsic, said Stern, Murugan and Matthew Pinson, the study's third author.

Their findings include a set of predictions for where to place hinges when designing folds, as well as for identifying problem areas and how to fix them—which could apply to everything from paper origami to micro-machines to self-assembling tents.

More information: Menachem Stern et al. The Complexity of Folding Self-Folding Origami, *Physical Review X* (2017). DOI: 10.1103/PhysRevX.7.041070

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