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Know When to Fold 'Em

Mathematicians get wrapped up in the world of origami

By LILA GUTERMAN

Start with a square piece of paper. Now, fold it into the shape of a tarantula.

Seem like a daunting task? It's not, if you borrow Robert J. Lang's software. The California-based origami designer -- who is, one day a week, a laser-physics consultant -- has created a program that computes the basic folds necessary to create the shape of practically any animal, fanciful or realistic.

Mr. Lang is just one of the researchers who have plumbed the mathematical underpinnings of paper folding. While his research helps origami designers create dragons and boars, it also aids physicists attempting to design an enormous telescope that will fold up to fit inside a rocket. Other researchers' work is getting at the fundamental mathematics that determines what shapes can and cannot be created by folding.

Although people have been making origami for centuries without the help of mathematical theories, the researchers say they have much to offer. "Math," says Thomas C. Hull, an assistant professor of mathematics at Merrimack College, "is a real natural way of looking at origami to try to understand it better."

Mr. Hull is largely responsible for the current surge of interest among mathematicians. He has enjoyed origami since he was 8 but didn't start thinking about its relationship to math until the early 1990s, when he was in graduate school at the University of Rhode Island. At that time, he read about a theorem that describes folds in the middle of a piece of paper. The creases resemble either mountains or valleys, depending on whether the paper is folded away or toward the person looking at them. The theorem stated that at every point where creases intersect, the numbers of mountain folds and valley folds will differ by two.

"I thought, 'Wow! There's math in origami,'" says Mr. Hull. But he soon discovered that the mathematics literature contained little about paper folding. He wondered, "How much of this origami math stuff could I try to prove on my own?"

In 1994, he published a paper, "On the Mathematics of Flat Origamis," which included a proof of the theorem about mountain and valley folds. As far as he knows, no one previously had proved that or several other basic theorems that describe paper folding.

The theorems relate to so-called flat origami -- any set of folds that leads to a structure that can be pressed, say, between the pages of a book without creating new creases in the paper. The famous paper crane is an example of flat origami. Three-dimensional origami is harder to describe mathematically.

Possible, but Practical?

Other mathematicians fed off Mr. Hull's enthusiasm and his forays into origami's mathematical theory. With his paper as inspiration, Marshall Bern, of the Xerox Palo Alto Research Center, and Barry Hayes, of PlaceWare Inc., a Web-conferencing company in Mountain View, Calif., wondered whether, with simply a diagram of crease lines, it is always possible to predict if the pattern will fold up to a flat origami model.

They proved in 1996 that it is not always possible, and that the question is equivalent in difficulty to other problems for which no efficient computer algorithms have been found. In the jargon of mathematics, a term used to describe such problems is "hard."

Other researchers are going beyond the fold in their exploration of possible shapes. Erik D. Demaine, an assistant professor of electrical engineering and computer science at the Massachusetts Institute of Technology, has proved that any conceivable flat origami shape can be folded from a piece of paper. But, he acknowledges, "this is a rather theoretical result. The method for doing this is completely impractical."

By contrast, Mr. Lang, the origami designer, looks to math for real-world help. A paper folder since age 6, he explores the mathematics of origami to help him design models.

In the mid-'90s, he created a computer program, which he calls TreeMaker, that provides the crease patterns for many flat shapes. Users just supply the program with a stick-figure version of the creature they wish to create, showing the relative lengths of legs, wings, body, head, tail, antennae, and horns. The computer program works out the creases to make, although it does not reveal the order in which they should be made.

Once the user figures out the order of the folds, the result is what Mr. Lang calls a base. It has an approximation of the shape of the final model but lacks much detail. The folder must use ingenuity, artistry, and more than a little skill in paper folding to change a triangular flap of paper into, for instance, a leg with a knee and a hoof. Mr. Lang offers his software free on the Web (http://origami.kvi.nl/programs/index.htm). Some of the tricks he uses to create paper sculptures appear in his new book, *Origami Design Secrets* (A.K. Peters, 2003).

He and Mr. Demaine now are working to create a program that will give crease patterns for three-dimensional origami models. "Erik approaches this from a formal mathematical, computer-science perspective: What is possible?" Mr. Lang says. "My interest is much more from the origami side, developing useful tools."

Folding Glass

Mr. Lang's techniques already have found use in the real world. Roderick A. Hyde, a physicist at Lawrence Livermore National Laboratory, sought his help in designing a huge, lightweight telescope that could fit inside a rocket. "You could crumple it up," says Mr. Lang, "but the crumples would distort the performance of the lens."

He came up with a way to fold 72 pieces of glass connected by hinges, and then unfold them to form a flat lens. Already, Mr. Hyde and his colleagues have built a prototype five meters in diameter. "It's the largest lens that's ever been built," Mr. Hyde says. The Livermore physicists intend to build a telescope with a lens 100 meters in diameter, in hopes of putting it into Earth orbit to detect faint, far-off planets around other stars.

Some people are aiming lower, using Mr. Lang's folding techniques to support a hobby or an art. Jan Polish, treasurer of OrigamiUSA, a group for enthusiasts, says young members are eager to explore the mathematical programs, although she suspects that most origami artists work more intuitively.

But Joseph Wu, an origami designer in Vancouver, British Columbia, says he follows the mathematical advances. His "holistic" process of designing complex pieces -- "new creations spring fully formed into my mind" -- relies at a subconscious level on new techniques pioneered by Mr. Lang and others, he says.

Even Luddites among origami devotees, Mr. Wu says, would acknowledge "that the introduction of hard mathematics into origami has led to advances in what we can do." Those techniques have enabled new levels of complexity, he says.

"Insects are a great example," he says. "The early traditional origami insects were very simple, blocky shapes -- rough approximations." But mathematics has led to the creation of paper insects that appear anatomically correct. "Now we don't talk about making a beetle. We talk about specific species of beetles."

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