The Helium Stockpile: A Collaboration in Mathematical Folding Sculpture

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ABSTRACT

The Helium Stockpile is a manipulable folding structure of hundreds of wooden blocks, representing the transformation between surface and solid through a foldable one-dimensional chain. The sculpture grew out of an unexpected collaboration between a sculptor and two mathematicians, giving the structure a mathematical basis through which it is guaranteed to be foldable into essentially any three-dimensional shape.

To discover correspondences between projects in wildly differing fields of research is like hearing a chord that resonates in multiple chambers. The long linear fingers of scientific expertise reach into increasingly exciting and highly specialized territories. Much contemporary art resembles scientific research in this way, encountering the problem of specialization and presuming an audience increasingly tolerant of obscurity. Links between art and science can help create a web, not limiting the reach of specialization but connecting these efforts laterally and spreading something of the collaborators' excitement (as well as understanding). The felicitous collaboration between Erik and Martin Demaine's work on complex folds in mathematics/computer science and Laurie Palmer's sculptural investigations might seem at first an unlikely link. It did not come about as a product of many conversations based in shared interests but in a single coup—the result of a mutual friend linking a question posed by the artist with a solution recently invented by the computer scientists. There has been delight on both sides in discovering that very different questions posed in different fields might be resolved in a single solution—conceived in relation to one field and generously lent to another in which it finds a different form and relevance. The result of this translation generates a material manifestation (with slippage, i.e. changing as it materializes) that can enter the world, concretized, while retaining something of the abstract at the same time.

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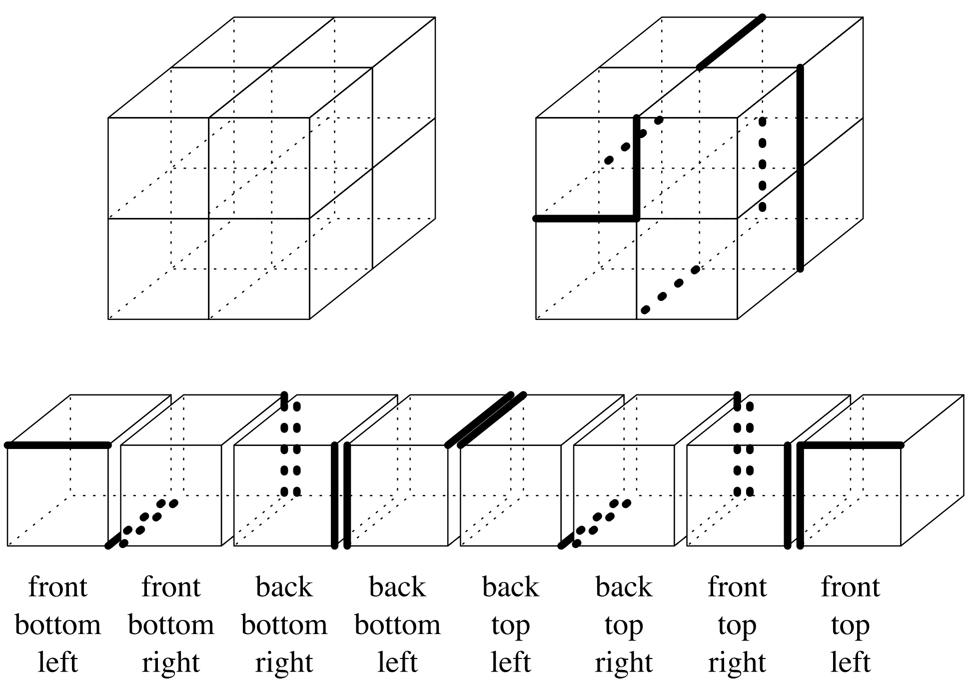


Fig. 1. A hinged dissection of a cube into a $2 \times 2 \times 2$ arrangement of subcubes (the units are shown as cubes without the $2 \times 2 \times 2$ subdivision, for clarity). (© Erik Demaine and Martin Demaine) The bottom chain (the bottom half of the figure) is an unrolling of the top-right hinging (the top half of the figure).

The Federal Helium Stockpile

This project began with a curiosity on the artist's part to see a floor fold up into an object, a field transform into a mass through folding, as well as to effect the reverse: to unfold an object to create a space. Spatial expanses that we call "land," for example, with their horizontality and extension, become transformed into commodities in a blatantly literal way through mining or quarrying; their materiality is transformed into something to buy: processed, packaged, slapped with a bar code and shipped off. Land is material, but more often thought of as place, something that one can walk, run or drive over. When one buys land one does not usually think of buying its materiality so much as the privilege to occupy a space, to walk there, to build there and to keep others from walking or building there. Perhaps one considers the fertility of its soil, but one rarely thinks of digging it all up and selling it. This sculptural project was conceived as a "transitional object," as redefined from D.W. Winnicott's specific use of that term in child development [1], but retaining its playful, half-real and half-imaginary flavor: as something that could move between (and thereby model a relation between) the expanded space that one might occupy and the contracted space that one might hold; between a place and an object. It also became an object through which viewers/players/participants might negotiate a relationship with an abstract-seeming but very real material and its storage site: The U.S. Federal Helium Stockpile.

The Federal Helium Stockpile in Amarillo, Texas, stores helium, a high-tech commodity [2], under pressure in the tiny pores of an underground dolomite formation. Helium's materiality is hard to grasp, literally or figuratively. As a gas it wants to escape and float up and out of the earth's atmosphere, which is why the stockpile was initiated in 1960, to preserve the earth's (actually the United States') limited but escaping supply. Because helium is a gas, however, and a particularly light one, it also nudges itself toward the category of space. At the helium stockpile, one can see all the paraphernalia and local detail surrounding the gas—the wellhead, the refrigeration tower, the lab, the fencing, the mesquite and the antelope—but nothing of the stuff itself. A guide might present a 1-inch sample cube of the dolomite into which the helium is injected, and it will seem as solid as a tabletop, not at all spongy or lava-like.

The Sculpture

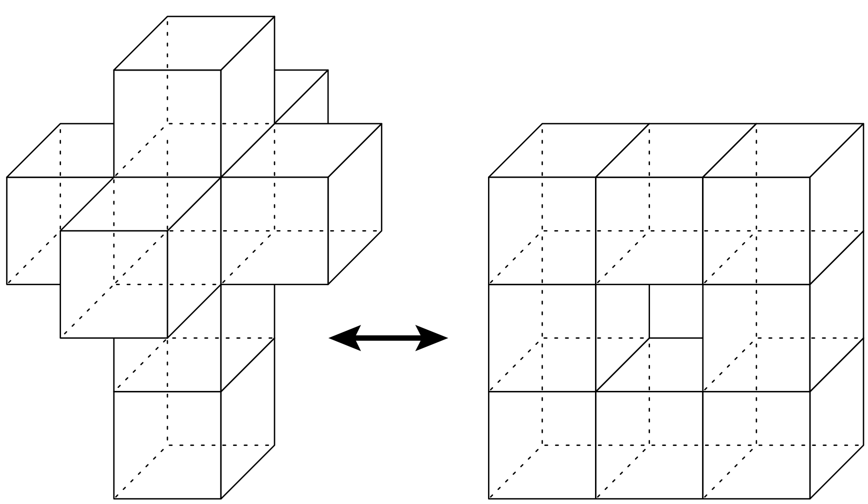
Helium, in its simultaneous presence and absence, its ambiguous categorization as material and space, became a referent from the experiential world (as distinguished from a world of abstract ideas) for this folding sculpture. The sculpture (Color Plate G) is made of finger-jointed poplar blocks; each block is hinged on two sides to other blocks, and the whole stockpile can be connected to form one long foldable chain, following a mathematical principle that guarantees that the chain can fold into a wide variety of shapes. Helium has two protons and two neutrons; it is the second-lightest element after hydrogen and was the second element to form, according to physics' origin story of the universe. Because helium's formation in the heat of a star (our sun is constantly producing helium) is the first step toward the formation of all subsequent heavier elements, helium might be thought of as a building block. Not only is each block in the sculpture hinged on two sides, but the basic mathematical folding unit is $2 \times 2 \times 2$, 8 blocks that fold into a rectangle 2 blocks high, 2 blocks wide and 2 blocks thick.

The processes through which our material world is continually produced are increasingly obscured from the average person, because advanced technologies are difficult to comprehend and access for most people and also because fewer and fewer people are employed at working with these technologies. The woodenness and dumb materiality of the stockpile makes it accessible and manipulable, but not without limits. The hinging creates a system of restraints at the same time that it allows unknown reconfigurations. To facilitate handling, the long chain of blocks has been broken into smaller segments.

A material is a system, with definite qualities and unknown potentialities. If these awkward building blocks—in their relation to the seeming immateriality of helium—can be played with, they might offer a means of imaginative engagement with the increasingly abstract material world and address its simultaneous abstraction and concreteness—the understanding that any material, not just helium, both is and is not "real."

The question at the heart of this project was prompted, on the artistic side, by philosophical works by Gilles Deleuze, Brian Massumi and Bernard Cache on folding, potentiality and change [3]. It also arises from one of the paradoxes of contemporary sculpture since the 1960s: that a work might be both object and process, thing and place (a site for temporal experience). Robert Smithson's series of *Site/Non-Site* works, comprising maps and containers of bulk materials from the mapped sites, are a classic articulation of this paradox in dialectical form. Carl Andre's floor grids turn the object-nature of his polished metal squares into a space-nature, making objects into places that could be occupied (except that they are usually protected by museum guards). The now-familiar role of the minimalist grid in resisting representational imagery and thereby making room for a focus on process is relevant here. However, the process in this work is tangibly participatory, the grid always

Fig. 2. The cross on the left and the donut on the right, and any other shape made up of 8 cubes, can be folded from the hinged dissection of 64 smaller cubes resulting from 8 copies of the basic unit from Fig. 1. (© Erik Demaine and Martin Demaine)



changing form, and the helium reference reaches out to engage the worlds of commerce and utility and science, which are never "outside" of art. Kenneth Snelson's tensegrity structures and his later models of atoms, as well as Alexandr Rodchenko's interpretations of atoms, are interesting antecedents, although this project, unlike them, is eminently participatory. A more accurate and always contemporary reference might be a set of Legos or a piece of paper with the creases still visible from folding by its former (brilliant) users.

The Mathematics

The pattern by which the sculpture hinges blocks together into a chain follows from a mathematical theory of three-dimensional "hinged dissections" [4]. This work grew out of an interest in the mathematical community in largely two-dimensional hinged dissections [5]. The basic unit for the hinging pattern is a slicing of a cube into a $2 \times 2 \times 2$ grid of subcube blocks and a hinging of these subcubes into a loop of blocks in such a way that there is at least one hinge on every side of the original cube. There are several such hingings that we could use as our basic unit; the sculpture uses the one shown in Fig. 1, which has the additional property that the blocks can be laid out flat.

The $2 \times 2 \times 2$ hinging structure can be repeated by joining together the loops of blocks for each basic unit into one long loop of many blocks. For each basic unit we add to the loop, we increase the number of blocks by 8. As a long loop of blocks is difficult to manipulate, we remove some of the hinges to partition the final loop into smaller chains for easier manipulation. While the mathematics is rooted in a situation where the original shape is a cube and the blocks are subcubes, the same principles work for any rectangular block shape—or indeed a more general shape called a parallelepiped—divided into a $2 \times 2 \times 2$ arrangement of similarly shaped but 8th-sized blocks.

What is special about this construction of a hinged chain of blocks, as opposed to countless other ways to string together a collection of blocks, is that the chain is guaranteed to be foldable into a wide variety of configurations. Specifically, it is proven that any connected 3D arrangement of $2 \times 2 \times 2$ basic units is a foldable configuration of the chain of blocks [6]. In particular, the chain can form a long linear structure, a flat 2D surface or a 3D solid. Figure 2 shows some examples of this flexibility. The number of different foldable configurations grows exponentially with the number of blocks, leaving the viewer with countless possibilities in manipulating the sculpture.

Acknowledgments

We thank our common friend Eli Ben-Sasson for his insight in connecting us at the early stages of this project. E. Demaine also acknowledges support from the National Science Foundation under CAREER award CCF-0347776 and from the Department of Energy under grant DE-FG02-04ER25647.

References and Notes

1. D.W. Winnicott, *Playing and Reality* (London: Tavistock Publications, 1971). "It is in the space between inner and outer world, which is also the space between people—the transitional space—that intimate relationships and creativity occur." D.W. Winnicott, "Transitional Objects and Transitional Phenomena," 1951, reprinted in *Playing and Reality*.

2. Helium's high-tech applications include its use as a non-reactive atmosphere for extruding fiber-optic filaments; for growing silicon and germanium crystals for semiconductors; and to cool the superconducting electromagnets that are used as containment walls for particle accelerators and nuclear testing; as well as for magnetic resonance imaging (MRI). Liquid helium, with a boiling point close to absolute zero, is the quintessential cryogenic material.

3. G. Deleuze, *The Fold*, foreword by Tom Conley (Minneapolis, MN: University of Minnesota Press, 1992); B. Massumi, *Parables for the Virtual* (Durham, NC: Duke Univ. Press, 2002); B. Cache, *Earth Moves*, Michael Speaks, ed., Anne Boyman, trans. (Cambridge, MA: MIT Press, 1995).

4. E.D. Demaine, M.L. Demaine, J.F. Lindy and D.L. Souvaine, "Hinged Dissection of Polypolyhedra," *Proceedings of the 9th Workshop on Algorithms and Data Structures*, Lecture Notes in Computer Science **3608** (2005) pp. 205–217.

5. For a comprehensive book on hinged dissections see G.N. Frederickson, *Hinged Dissections: Swinging and Twisting* (Cambridge, U.K.: Cambridge Univ. Press, 2002). A major influence in encouraging the exploration of this area, as well as connections between mathematics and other disciplines such as art, is Martin Gardner; his mathematical books are now collected on a CD, *Martin Gardner's Mathematical Games* (Washington, D.C.: The Mathematical Association of America, 2005).

6. Demaine et al. [4].

Manuscript received 21 March 2005.

Erik D. Demaine's research is at the intersection of mathematics and computer science. He is the Esther and Harold E. Edgerton Professor and Associate Professor in Electrical Engineering and Computer Science at the Massachusetts Institute of Technology. His papers with over 150 collaborators explore many different avenues of algorithms and geometry.

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