emerging: defining the terms

What is "Self Organization"?

The physicist Richard Feynman once described how aliens from outer space looking at the earth would, to their astonishment, see a thin vertical line of millions of people brushing their teeth that rotated around the earth every 24 hours. This line of toothbrushers, just on the bright side of the line of dawn that separates day and night, is not created by a single tyrant that orders each of those people to brush their teeth at the just the right moment. Rather it is formed by the individual actions of millions of people who have each independently decided to brush their teeth in the morning. Nobody has ordered them to form a line, yet each acting independently has generated a distinctive pattern in space and time. This line and its motion around the earth is an example of "self-organization", that is, when a global pattern emerges from the rules that govern a large number of individual units. What has fascinated scientists most about self-organization is that these beautiful global patterns can rarely be anticipated from the simple rules that govern the behavior of the myriad of their individual units.

There can be many different types of individual units. The rules that control them can be mathematical rules, physical laws, or biological behaviors. Yet, under these rules, the individual microscopic units can paint beautiful global patterns across space and time. Let's see some examples of self-organization from biology, physics, and mathematics.

How the Leopard Gets its Spots.

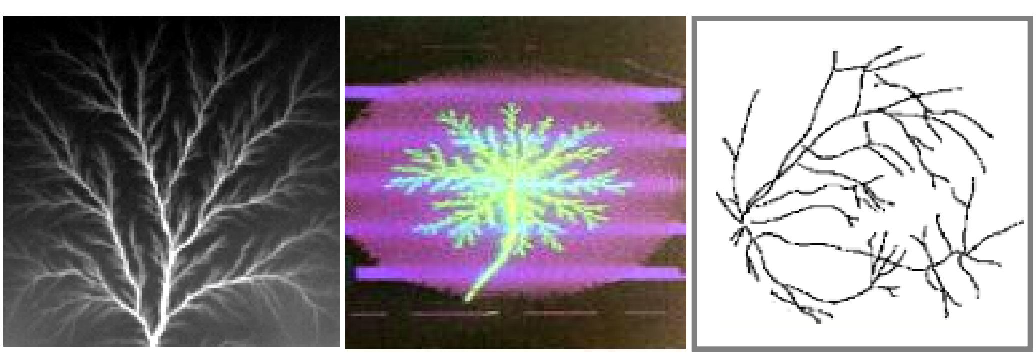
How does an embryo of identical cells form itself into a human being of so many different cells shaped into so many different parts? Alan Turing was a genius who invented a machine that in principle could solve any mathematical problem and helped to break the German codes during World War II. In a seminal article in 1952 he showed that molecules alone could form patterns in

Leopard spots are an example of self-organization.

space. If the fate of the cells depends on their position in these patterns, a human being could be formed. How can molecules form patterns? Let's say the molecules chemically react with each other, but in a special, though still pretty simple way. Over small distances the chemical reactions enhance each other so that their chemical product builds up to high levels, but over long distances the chemical reactions inhibit each other, so that their chemical product is scarce. Small disturbances will enhance themselves and grow large, inhibiting the spaces between them. Depending on the geometry of where the molecules react the high levels of chemical product can form spots or bars. James Murray (1988, 1989) showed that if the chemical product results in skin pigment this could paint the stripes of the zebra or the spots of the leopard. His calculations also showed that the markings on the tail of an animal must always change from spots where the tail is thick near the body to stripes where the tail is thin at the tip, just as is found in nature. The independent chemical reactions of a trillion trillion molecules (approximately) can self-organize to form the patterns on the coats of cats and goats.

Lightning, Water, and Blood.

Many different physical, chemical, or biological mechanisms can self-organize microscopic pieces into strikingly similar global patterns. How can this be? How can electricity sparking through an insulator, water being pushed into oil, and blood vessels growing in the retina of the eye all self-organize into similar patterns? The answer is that the equations that describe each of these different processes all have the same mathematical form, even though the symbols in the

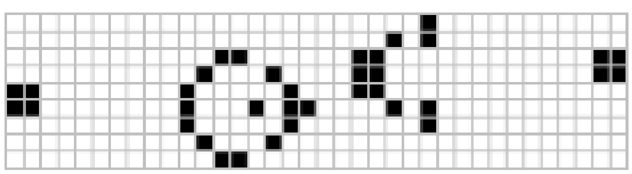


From left: Electricity, oil in water, and blood vessels all self-organize into strikingly similar patterns. How does this happen? It's all simple math.

equations represent different natural things in each case. The pattern is produced by the mathematics. In each case, as represented in the equations, the flow of electricity, the push of the water, the growth of blood vessels is strongest where the pattern is sharpest, which is at its tips. So the tips grow, until by chance they divide, and now the growth is strongest at each new tip, so now they both grow. Each tip grows and branches, branches and grows. No hand paints the overall pattern, it is the self-organization of many racing electrons, pushing molecules of water, or growing cells that self-organize into the extensive and delicate and ever branching tree.

Pure Thought and Endless Motion.

Perhaps the purest and most surprising forms of self-organization are seen when we ourselves make up the simple rules and we then marvel at the unanticipated patterns that they produce. An example is the "game of life" formulated by the mathematician John Conway (M. Gardner, 1970). On an endless piece of graph paper each box can be "alive" or "dead". At each play of the game, every living box with two or three neighboring boxes that are alive survives; every living box with four or more neighbors dies from too many greedy neighbors; every living box with one neighbor or none dies from isolation; and any dead box adjacent to exactly three neighbors gives birth to a living box. With these few simple rules, and some starting boxes that are alive, patterns ebb and flow, explode, travel to infinity, or form complex structures than continue to grow or slowly die into emptiness. Play for yourself using the Java applet at the website http://www.bitstorm.org/gameoflife/ . These boxes are technically called *cells*, and with the rules that animate them they are called *cellular automata*. The game of life is only one set of such rules. So complex are the results of such simple rules that Stephen Wolfram (2002) has proposed that the laws of nature can be represented by these cellular automata, rather than the equations of calculus that we have used to represent them over the last 300 years. He argues that the complex patterns of the entire world around us are the result of the self-organization of many tiny cells each independently following their own quite simple rules. ■



In Conway's famous "Game of Life", a set of simple rules produces striking and complex animated patterns.

by: Larry S. Liebovitch, Interim Director,
Center for Complex Systems and Brain Sciences at Florida Atlantic University
http://walt.ccs.fau.edu/~liebovitch/larry.html

References

- A. M. Turing. 1952. *The chemical basis of morphogenesis*. Phil. Trans. Roy. Soc. London B237:37-72.
- J. D. Murray. 1989. *Mathematical Biology*. Springer-Verlag, NY, pp. 435-448.
- J. D. Murray. 1988. *How the leopard gets its spots*. Sci. Amer. 258(3):80-87.
- E. Guyon and H. E. Stanley, 1991. *Fractal Forms*, Elsevier/North Holland.
- M. R. Tetz and D. J. Apple, 1990. *The Ocular Fundus*. Williams & Wilkins, Baltimore.
- M Gardner. 1970. *Mathematical Games: The fantastic combinations of John Conway's new solitaire game "life"*. Scientific American 223 (October 1970): 120-123.
- S. Wolfram. 2002. *A New Kind of Science*. Wolfram Media Inc, Champaign, IL.

Images:

- Leopard image from J. D. Murray, 1988, www.resnet.wm.edu/~jxshix/math490/murray.doc
- Lightning image from http://www.sgsmp.ch/lichtenberg.htm
- Oil image from E. Guyon and H. E. Stanley, 1991, Plate 12
- Blood vessels image traced from M. R. Tetz and D. J. Apple, 1990
- Game of Life image image from http://en.wikipedia.org/wiki/Image:Game_of_life_glider_gun.png