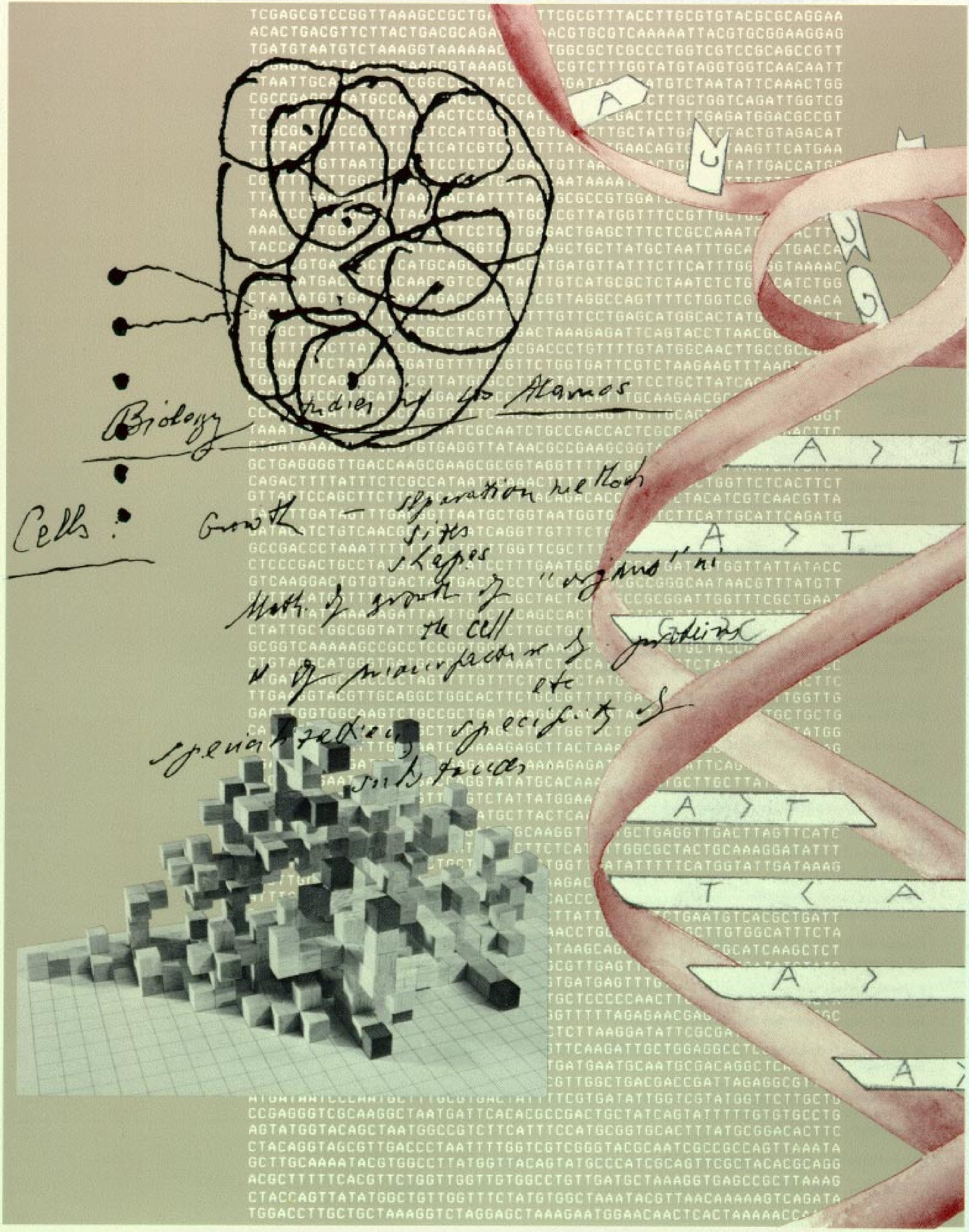

Biology
Cells:
Growth
sizes
shapes
the cell
etc

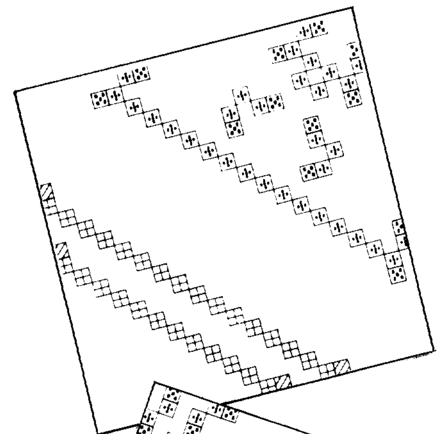
BIOLOGY

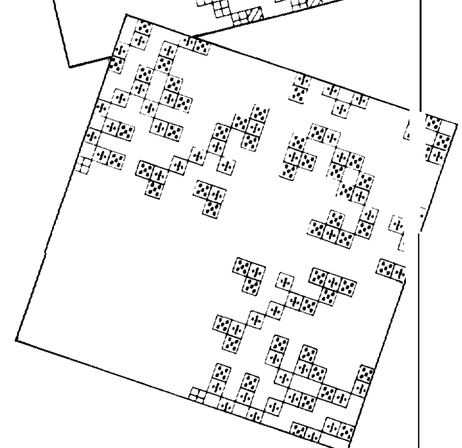
Ulam's genius for addressing basic questions in biology through simple mathematical models has already been encountered. In the mathematics section Hawkins and Mycielski introduced Ulam's notion of "genealogical" distance, a measure of shared ancestry. This was one among several extensions of the theory of branching processes invented by Ulam to answer questions in population dynamics and evolution.

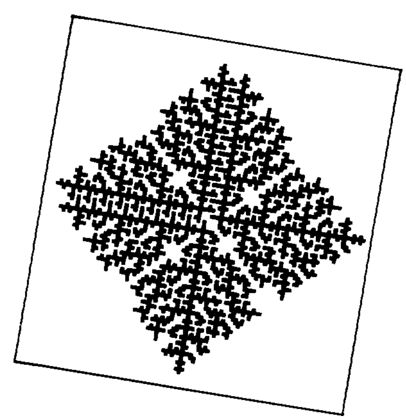
Another area that has had even more impact is Ulam's early work on cellular automata in which he and Schrandt demonstrated how complex patterns can evolve from simple initial conditions by applying a few simple recursion rules over and over again. The idea behind these computer studies hinges on a basic question in developmental biology: How does a human being develop from a single cell, a single fertilized egg? Certainly, with 10^{12} cells and only 10^{6} genes, there are not nearly enough genes for each cell to have its own gene. Stan proposed that genes encode not just simple rules, but rules of a higher logical type that change the simple instructions, in other words "rules for the change of rules" that become operative in response to events outside the cell but in contact with it. Stan began investigating this idea by making what he called kindergarten rules and applying them to a small number of cells. In one set of rules, cells multiply along a straight line until they meet another cell at which point their line of propagation rotates by 45 degrees. Rules of this sort were run on the computer to produce patterns resembling those found in nature, such as the vein distribution in a leaf or the pattern of a capillary bed. (Several figures from these studies with Schrandt are shown on the next page.) Recent work by Gerald Edelman of Rockefeller University on morphogenesis lends credence to Ulam's basic idea of "rules for the change of rules." Edelman's work suggests that form arises through an interaction involving adhesion molecules on the cell surface that alter the primary processes of cell development. "In this case, the modifications of the rules correspond to the developmental process of induction. For during induction, as a result of associations between adjacent groups of cells, particular cells undergo alterations in their properties through the process of cell differentiation, and these alterations, in turn, modify their subsequent interactions." (This quote is from an article by Leif Finkel and Edelman in volume 10, numbers 2 and 3 of *Letters in Mathematical Physics,* a special volume in memory of Stan Ulam.)

Ulam's cellular automaton models of growth patterns were just a start. Now cellular automata of various kinds are being used to model the complex networks associated with food webs and kin selection, and even neurons in our brain.

Stan was deeply interested in the organization and function of the human brain and the structure of memory. In the Gamow Memorial Lecture of October 5, 1982 (which is published here for the first time), he outlined some speculations about the mechanism







that allows us to recognize the alikeness of members of a class (for example, chairs) and the difference between two classes of objects (chairs and tables). In the same article referred to above, Finkel and Edelman comment on those ideas:

"Ulam was concerned with the problem of categorization—how to group objects on the basis of similarity and dissimilarity. Together with the related problem of generalization—how to define a class given only a few exemplars-this constitutes perhaps the most profound problem in biology. Ulam put forward the idea of generalizing the Hausdorff metric to deal with classes of objects . . . He had proven in an early paper that various compositions of two nonlinear transformations can, with some degree of accuracy, deform any plane figure into any other. If such a set of transformations are applied separately to two objects, two classes of related objects are generated. Ulam defined a generalized Hausdorff metric between these two classes that characterizes the 'similarity' of the two original objects. He pointed out that such a recognition system would yield a substantial saving in memory since, given the transformation mechanism, only one generating member of each class need actually be stored. Applying the transformations to new inputs and/or to stored memories would then allow matching between the two based on the metric, Inputs which did not match any of the stored memories might be stored as new memories . . .

The process of generating a class from a single object is used as a mechanism in the immune system, the biological recognition system concerned with recognizing foreign substances in the body. In this case, the transformations are effected by several mechanisms, including somatic recombination in the genes coding for the antibody molecules. [Edelman] has . . . demonstrated . . . that introducing these transformations in a repertoire of recognizing elements can actually improve the recognizing ability of the system.

With regard to pattern recognition by the brain, there are no currently known mechanisms to generate such transformations in the central nervous system. However, one of the outstanding problems of psychophysics is the mechanism responsible for so-called visual constancies. These are the invariant properties that allow us to recognize objects regardless of their spatial location or orientation (i.e., after arbitrary translations, rotations, zooming, etc.). Such a transformation generating mechanism, if present at some low level of the central nervous system, might account for these phenomena."

The question of similarity and dissimilarity, so important to recognition, comes up in a different form in the context of DNA. Here Ulam invented a new kind of metric space to measure the "distances" between the sequences of nucleotides that make up DNA segments. Walter Goad, one of Stan's "influencers" at Los Alamos, describes this invention and discusses its importance for the human genome project and for tracing the evolution of life. Summing up his experience working with Stan on both biological and weapons-oriented problems, Walter comments, "Stan habitually turned things to view from a variety of directions, much as he would see an algebraic structure topologically, and vice versa, and often supplied the connection that dispelled a gathering fog."