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Landscapes of Change: Boccioni's *Stati d'animo* as a General Theory of Models

1. Umberto Boccioni, study after *Quelli che partono*, 1912

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Matter, according to Henri Bergson, is made up of "modifications, perturbations, changes of tension or of energy and nothing else."[1] The forms of life differ from this only in their greater complexity of organization and their capacity to overcome torpor,[2] for both are immersed within the same universal stream of duration and constitute not different entities, but rather different modalities, of a single *élan vital*. Yet even as Bergson wrote, life was no longer so surely, nor by so great a magnitude, the most complex nor the most autonomous entity in the universe. For during the same years, the mathematician Henri Poincaré was discovering, to his own horror, that the mechanics of just three moving bodies bound by a single relation — gravity — and interacting in a single isolated system produced behavior so complex that no differential equation, neither known nor possible, could ever describe it.[3] Poincaré's discovery showed that evolving systems with even very few parameters may quickly be deprived of their deterministic veneers and begin to behave in a seemingly independent (random) fashion. What this meant was that it was no longer possible to show that one state of nature followed another *by necessity* rather than by utter caprice. Time, in other words, reappeared in the world as something *real*, as a destabilizing but creative milieu; it was seen to suffuse everything, to bear each thing along, generating it and degenerating it in the process. Soon there was no escaping the fact that transformation and novelty were the irreducible qualities that any theory of form would need to confront.[4]

It was no wonder that futurism — the social movement most deeply sensitized to cataclysmic perturbations — was obsessed with *complexes*: delirious, infernal, and promiscuous. For the very ethics and physics of the futurist program, conceived as an open, far-from-equilibrium system, responsive to and willing to amplify every destabilizing fluctuation in the environment, necessitated its multiple impregnation both in and by the social, material, and affective systems that surrounded it. The futurist universe — the first aesthetic system to break almost entirely with the classical one — could properly be understood only in the language of waves, fields, and fronts. The type of movements it was obsessed by were those that carved shapes in time not space; it studied the stabilities achieved through homeostatic knots of force in perpetual strife, it embraced the beauty and evanescence of becoming.

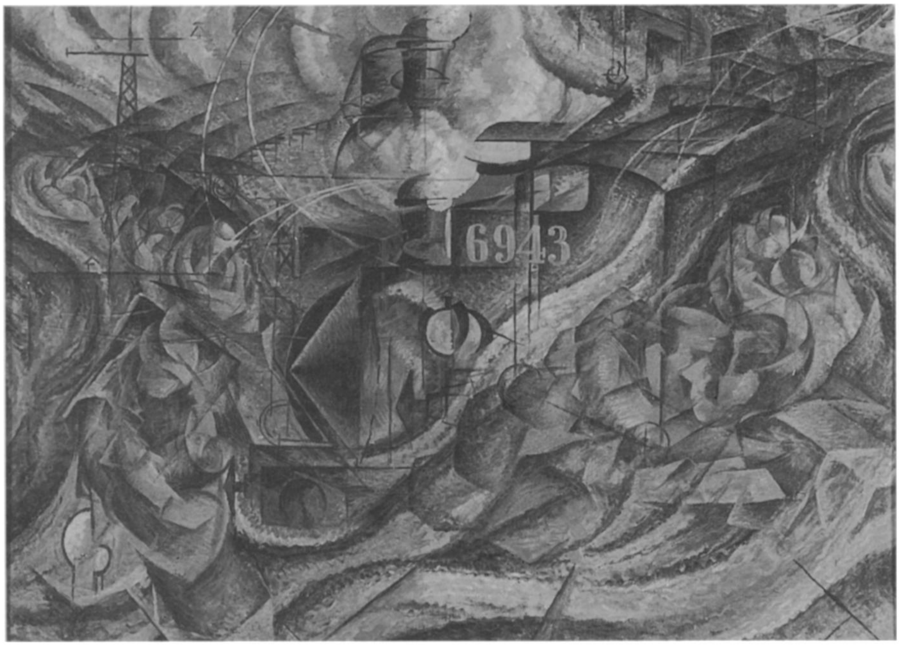
Yet futurism's profoundest gift to our century was its seemingly hubristic attempt to link the biosphere and the mechanosphere within a single dynamical system.

Umberto Boccioni's three-painting series *Stati d'animo* belongs to this project and as such comprises the first purely *modal* paintings in the history of art since the late medieval period.[5] The spatiotemporal locus of the train station scene is here splintered and kaleidoscoped into so much elementary matter, but only the better to be redeployed *intensively*, like sounds in a musical continuum or topological flows on a two-dimensional plane — scattered, accelerated, accreted, collided into three entirely distinct surfaces, or developmental fields. One scene, but three modalities of inhabiting matter. As prime exemplars of modal complexity, it was natural that railroad stations should play a privileged role in futurist practice; they were the first literal, complex systems of material flows manifested at a phenomenal scale whose associated forms could be apprehended as such, understood and actively engaged. The dynamical and morphological phenomena associated with this type of multiple *convergence* of flows have already been developed in relation to this work.[6] But the middle panel in the *Stati d'animo* series, *Quelli che partono*, seems to belong to an opposite but related problem, and one that deserves serious attention. *Quelli che partono* no longer describes a convergence of flows but rather the event of their breaking up, or bifurcation.

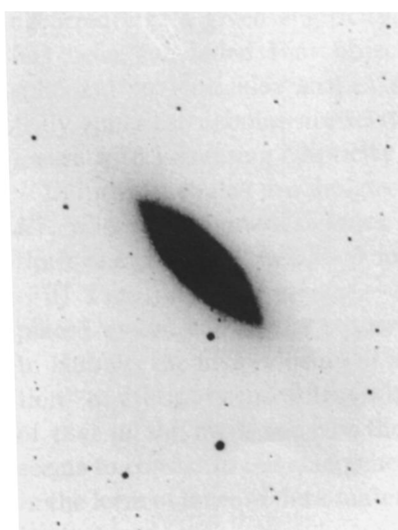
What does it mean, then, when something stable and continuous ceases to be so? What does it mean when the unfolding of a dynamical process suddenly shifts into a new mode, when an ensemble of units and forces breaks up to form two or more independent, more highly organized systems? The painting *Quelli che partono* wedges its own diagonal cascades and chevron forms between its two neighbor panels: on one side, the undulating, orbicular, systolic-diastolic processes of organicism and embrace depicted in *Gli addii*, and, on the other, the inertial, gravity-subjugated, vertical striations of *Quelli che restano*. The fullness and roundness of the first work is not simply one field of shapes among three, but rather the very plenitude from which the other two are derived. Between the first panel and the other two, there has taken place a *catastrophe*.

But before we can understand what this means it will be necessary to understand precisely what a form is, how it arrives, and why the "form problem" has been so difficult to handle. Most classical theories of form are limited by a major shortcoming: they are unable to account for the emergence, or genesis, of forms without recourse to metaphysical models. One of these classical theories — perhaps the paradigmatic one — is the so-called hylomorphic model. According to this model an independently constituted and fixed form is understood to be combined or impressed with a certain quantity of *hylé*, or matter, itself conceived as a fundamentally inert, homogeneous substance. Once brought together, these two abstract elements are said to form a thing. Yet, as we will see, a form can no more be fixed and given in advance (in what space would this work of forming be done?) than can "matter" seriously be considered to be either static or homogeneous.[7] Much of this perennial misunderstanding found itself recapitulated throughout our modern scientific tradition because it lent itself well to reductionism and controlled quantitative modeling. Reductionism is the method by which one reduces complex phenomena to simpler isolated systems that can be fully controlled and understood. Quantitative methods, on the other hand, are related to reductionism, but they are more fundamental, because they dictate how far reductionism must go. According to them, reductionism must reduce phenomena to the ideal scale at which *no more qualities exist within a system*, until what is left are only quantities, or quantitative relations. This is, for example, the basis of the Cartesian grid system that underlies most modern models of form.[8]

The classical grid system does not, strictly speaking, limit one to static models of form, but it does limit one to *linear* models of movement or change. A linear model is one in which the state of a system at a given moment can be expressed in the very same terms (number and relation of parameters) as any of its earlier or later states. The differential calculus of Newton is precisely such a model describing flows on the plane (differential equations are mechanisms that generate sets of continuous numerical values that, when fed into Euclidean space, appear as linear movement). But if the standard calculus can successfully model the evolution of successive states of a system, it can do so only insofar as it plots the movements of a body within that system, *and never the changes or transformations that the system*

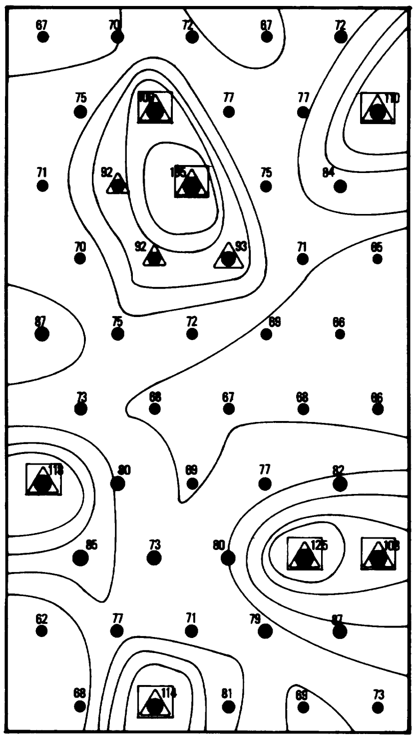


2. Boccioni, *Gli addii* (Farewells), 1911

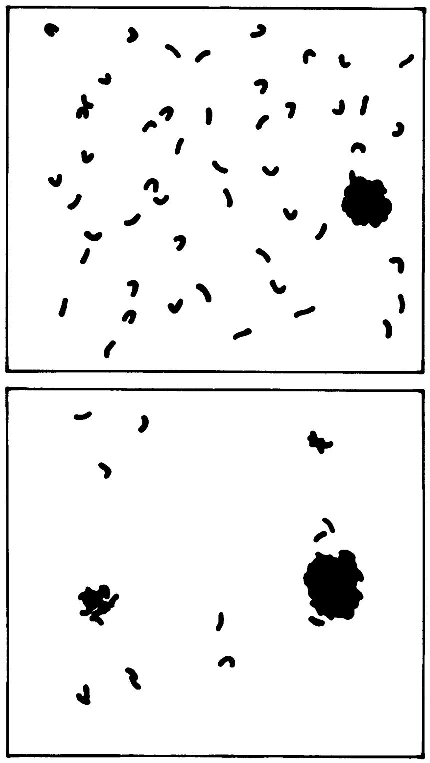


3. Spiral Nebula NGC4530 in its young, still spheroid, ringless state

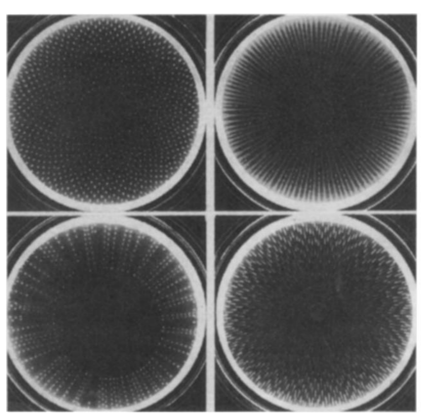
4. The cell, or blister, form of the sand domes that appear on a beach at low tide are the result of an "exfoliation" (the emission or release of a new surface or fold) triggered by a conflict of regimes (an encounter of forces whose sum will deform the system in a particular direction) in the neighborhood of a so-called butterfly catastrophe. The butterfly acts as an organizing center for a shock wave that "knits" the three evolving fronts into a pocket as it passes through them. The blister, or dome, is the morphogenetic "smoothing" of the instabilities introduced by the original conflict.



5. Christaller model showing symmetry breaking and the resultant complexity that arises in an initially homogeneous (point) field through even the most rudimentary feedback mechanisms between the individual points. The diagram models economic activity as it distributes itself in a geographical space, carving up the field almost randomly into centers, epicenters, and satellite regions. This is due to the proliferation of nonlinearities in the evolutionary mechanism and its extreme sensitivity to purely chance factors that are continually recycled back into the system, magnifying their effects.

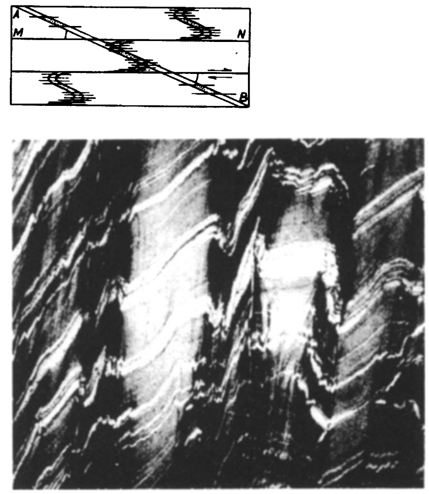


6. Coleoptera larvae self-aggregating. A gradient field (a field of graduated differences registered by chemical concentrations or some other effector-substance) naturally arises as the larvae begin to emit pheromones into the environment in direct proportion to their level of nourishment. The larvae then begin to migrate toward regions of greater pheromone (and food) concentration, which, in turn, both increases the concentration and steepens the gradient until a definitive cluster is formed. If the field is initially homogeneous but very dense, diffusion of information will be very rapid and will soon result in a single large cluster. If the field is initially homogeneous but sparse, signals will be weak and not oriented, resulting in no definitive clustering. For values in between, any number of clusters may be sustained, though only if they are arbitrarily established at the outset. The larger the initial size, the greater the chance of a given cluster to persist over time.



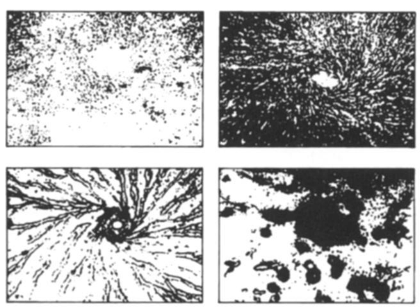
7. Escherichia coli bacteria in petri dishes cluster together into regular, radial patterns of bunched cells to protect themselves from noxious chemicals or stimuli (for example, antibiotics). The chemotactic signals that trigger the formation of the patterns are amino acids secreted by each individual bacterium. The clustering is induced by feedback mechanisms between the bacteria themselves.

8. Boccioni, *Quelli che partono* (Those who leave), 1911

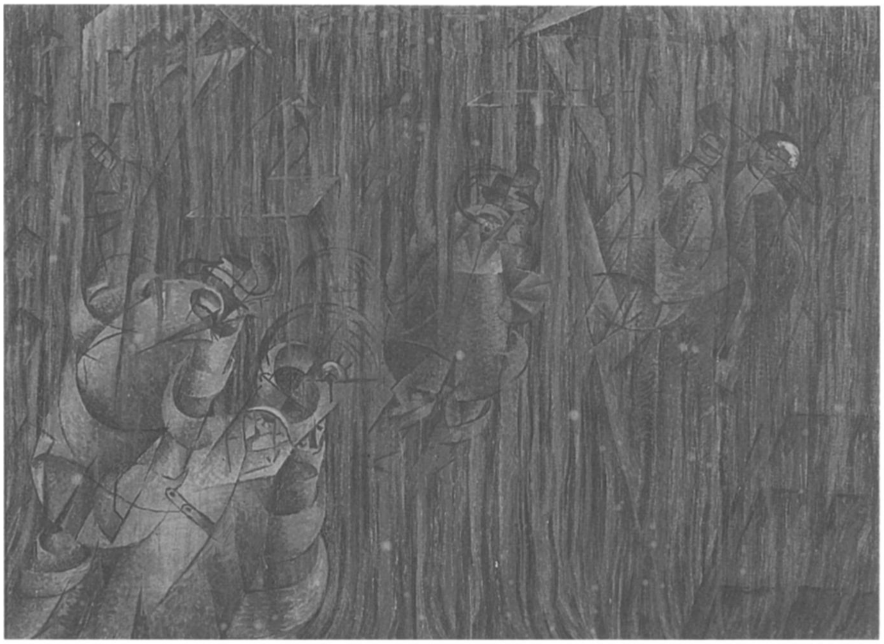


9. Gleitbretter shearing in sandy slate. The faulting pattern is caused by the superimposition of two simultaneous laminar catastrophes, shearing and folding.

10. Nebula NGC4594, a giant, brilliant but much older galaxy breaks into two distinct stellar populations — the old stars forming a spherical halo, the new ones collecting on the much less dense central disk.

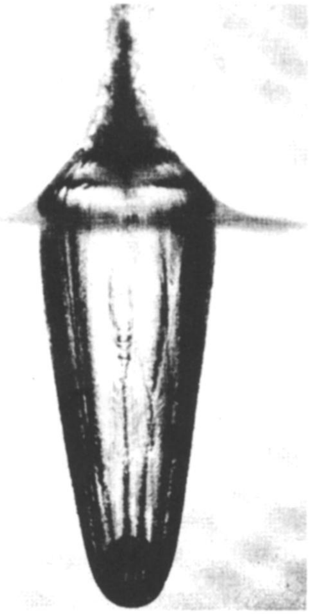


11. Development of a spiral aggregation wave in the dictyostelium slime mold. A remarkable, complex series of events takes place that gives shape and organization to an initially homogeneous field of individual amoebae. The first break in symmetry — a cell-free space in an even lawn — becomes the focus for a global spiral wave that first orients the cells, then gathers them into "streamers," drawing them toward a doughnut ring that surrounds the initial center. Position in the field and responses to chemotactic pulses causes the cells to differentiate functionally from simple relay elements to complex, self-entraining oscillators. Suddenly, organized and synchronized waves pass through the field, directing the amoebae to form a single semispherical mound (on the spot of the original void) and a single differentiated multicellular organism with a foot, capable of migrating significant distances in search of new sources of food.



12. Boccioni, *Quelli che restano* (Those who stay), 1911

13. Cusps on a beach illustrate generalized, periodic, cascade catastrophe in water and sand.



14. Cavity produced behind a sphere dropped in water. A reaction splash (above surface) illustrates Thom's elliptical, or filament, catastrophe.

itself undergoes. Indeed, not only the system but also the body that moves through it is condemned to perpetual self-identity: for it, too, can change only in degree (quantity) and never in kind (quality).[9] Further, these types of smooth continuous changes are not true changes at all, at least not in the deep qualitative sense that we would need to explain the genesis or appearance of a form.

Modern topological theory, largely introduced by Poincaré, offered a decisive breakthrough with respect to the limitations of these systems. On the one hand, it entailed the revival of geometrical methods to study dynamics, permitting one visually to model relationships whose complexity surpassed the limits of algebraic expression; on the other, it permitted one to study not only the translational changes within the system but the qualitative transformations that the system itself undergoes. The classical calculus of Newton and Leibniz was developed along the lines of a ballistic model, the plotting of trajectories of real bodies against an inert, featureless, and immobile space whose coordinates could be exhaustively described in purely numerical terms (x, y). Topology instead describes *transformational events* (deformations) that introduce real discontinuities into the evolution of the system itself. In topological manifolds the characteristics of a given mapping are not determined by the quantitative substrate space (the grid) below it, but rather by the specific "singularities" of the flow space of which it itself is part. These singularities represent critical values or qualitative features that arise at different points within the system depending on what the system is actually doing at a given moment or place. It is just this variability and contingency that is of great importance.

What exactly are these singularities? In a general sense, singularities designate points in any continuous process (if one accepts the dictum that time is real, then every point in the universe can be said to be continually mapped onto itself) where a merely quantitative or linear development suddenly results in the appearance of a "quality" (that is, a diffeomorphism eventually arises and a point suddenly fails to map onto itself).[10] A singularity in a complex flow of materials is what makes a rainbow appear in a mist, magnetism arise in a slab of iron, or either ice crystals or convection currents emerge in a pan of water. Some of these singularities bear designations — "zero degrees Celsius," for example, denotes the singularity at which water turns to ice or ice back to water — yet most do not. Thus matter is not in any sense homogeneous, but contains an infinity of singularities that may be understood as properties that emerge under certain, but very specific, conditions.[11] What is crucial about all of this is the following: both "ice" and "water," as well as "magnetism" and "diffusion," are *forms*, and they are all born at and owe their existence to singularities. Indeed, there is no form anywhere that is not associated with at least one (though most likely more than one) singularity.

In topology singularities of flows on the plane are more limited and specific but can give rise to enormously complex and variegated behavior. These have already been classified in various ways, most often as attractors and separatrices whose varieties and combinations give rise to specific qualities and behaviors: sinks, sources (repellors), saddles, and limit cycles. Each of these describes a particular way of influencing the movement of a point in a given region of the system or space.[12] Now clearly, a plane is a very simple, even rudimentary space. A flow in the plane can essentially be described by two parameters, or two degrees of variability or "freedom." Most systems in the real world, that is, most forms or morphogenetic fields, are clearly more complex than this. Yet it is enough to understand how forms emerge and evolve in simple "2-space" to gain an appreciation of how more complex forms evolve in more complex spaces. What is central here is the *dynamical* theory of morphogenesis, which characterizes all form as the irruption of a discontinuity, not *on* the system but *in* it or *of* it. For a form to emerge, the entire space (system) must be transformed along with it.

This type of local but generalized transformation is called a catastrophe. A catastrophe describes the way in which a system — sometimes as a result of even the most infinitesimal perturbation — will mutate or jump to an entirely different level of activity or organization. Now it is a basic tenet of the laws of thermodynamics that in order for something to happen within a system, there must first be a general distribution of *differences* within that system. In dynamics these are called "potentials" or gradients and their essential role is to link the points in a system and draw flows from one place to another. A potential is a simple concept:[13] anything sitting on one's desk or bookshelf bears a potential (to fall to the floor) within a system (vector field) determined by gravity. The floor, on the other hand, is an attractor because it represents one of several "minima" of the potential in the system. Any state of the system at which things are momentarily stable (book on the shelf or on the floor) represents a form. States and forms, then, are exactly the same thing. If the flow of the book on the shelf has been apparently arrested, it is because it has been captured by a point attractor at one place in the system. The book cannot move until this attractor vanishes with its corresponding basin and another appears to absorb the newly released flows. The destruction of the attractor (and the creation of a new one) is a catastrophe.

Now before developing this theory further it will be necessary to make a few observations. It appears, in a certain sense, that the concept of form has been defined as a state of a system at a particular point in time. In fact, forms represent nothing absolute, but rather *structurally stable moments* within a system's evolution; yet their emergence (their genesis) derives from the crossing of a qualitative threshold that is, paradoxically, a moment of structural *in*stability. This is possible because forms are not simply systems understood in the classical sense, but belong to a special type known as "dissipative systems." A dissipative system or structure is an open, dynamical system. By "open" one means that it is an evolving system, like a pot of coffee or the local weather, that has energy (information) flowing out of it, and likely into it as well. From where does this energy come and to where does it go? It comes from other systems, both those contiguous to it and those operating within it or upon it: that is, *at entirely different scales of action*. We will see what this means in a moment. For now, one need only note that it is the continual feeding and siphoning of energy or information to and from a system that keeps the system dynamic — simultaneously in continual transformation locally and in dynamic equilibrium globally. The flow of energy through a system ensures the following:

1. That information from outside the system will pass to the inside. The effects of this simple operation are actually very complex: the outside of the system becomes slightly depleted in the process and transformed in its capacities and potential energies; the operation affects the inside by perturbing its flows ever so much away from their equilibria or attractors, "priming" the system for potentially creative disturbances (morphogenesis). It also carries energy or information from inside the system to outside, producing these same effects now in reverse.

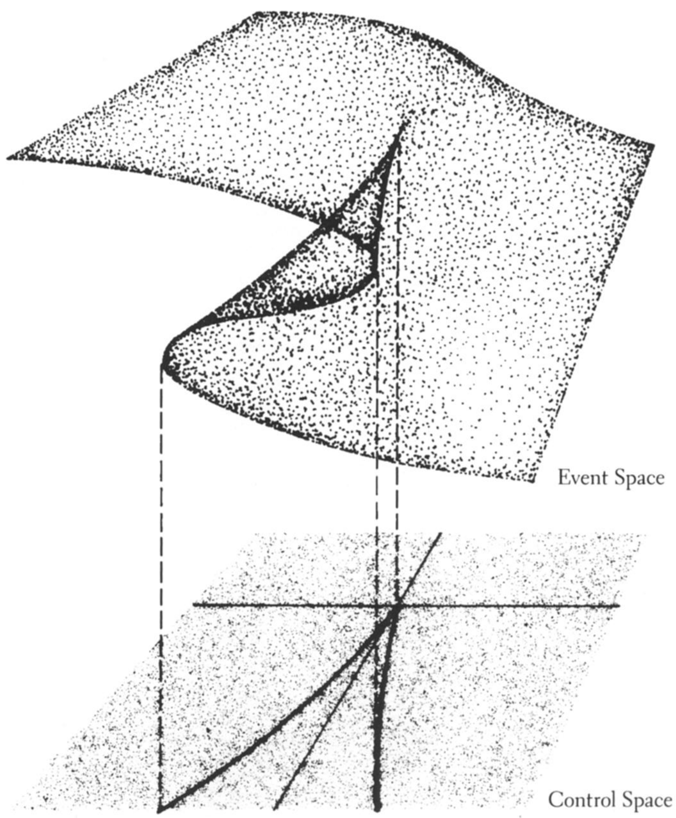
2. That information from certain levels in the system is transported to other levels, with results that may be very dramatic.[14] What one means by dramatic is simply this: certain parts, or strata, of the system may already have absorbed as much energy as they can hold *in their current stabilized configuration*. Any change at all, no matter how tiny, will precipitate a catastrophe (a morphogenesis), forcing the system to find a new equilibrium in the newly configured field. The effect of these liberated and captured flows on the neighboring systems creates an algebraic problem too complex (because full of nonlinearities) to predict. Qualitative modeling has a chance, however, because at the very least it offers analytic precision where before there were only "black boxes" of mysterious, irreducible forces.

It is the property of every dissipative system perpetually to seek a rest state or equilibrium where it will remain until another threshold in the system's dynamic is crossed. Again, figures of structural stabilization gather around singularities that themselves are defined dynamically, for these, too, can be maintained only at a certain energy cost. Every real system is made up of other systems, and they are all continually leaking information to one another in such a way as to link them across a single "continuum of influence."[15] All the forms of the universe are produced as by-products or maps of particular evolutionary segments of one or another dynamical system. Indeed, forms are not fixed things, but continuous metastable *events*.

Catastrophe theory is one method for describing the evolution of forms in nature. It is essentially a topological theory that describes the behavior of forces in space over time, but its techniques have been extended to many real world phenomena, such as the forming of tools, the capsizing of ships, embryology, and psychology (anorexia nervosa, fight-flight theory). This is possible because the behavior of real forces in real space (forces applied to a beam, weight poorly distributed in a ship's hull) follows exactly the same rules as forces modeled in complex (topological, parameter, or "phase") space.[16] Catastrophe theory recognizes that every event (or form) enfolds within it a multiplicity of forces and is the result of not one, but many different causes. Let us look at how this is done.

Catastrophe theory is a fundamentally Heraclitean "science" in that it recognizes that all form is the result of strife and conflict. It shows that the combination of any two or more conflicting forces may result in entirely irregular and discontinuous behavior if allowed to interact dynamically. This means that if one plots these forces on a plane as intersecting at a point, each force will be affected unequally as the point is moved in any direction. The effects of this initial difference produced in one of the forces may simply be compensated for, or absorbed by, a proportionate gain in the opposite force; but it may also happen that a small drop in the first force will trigger a gain in a third force that will diminish the second force to an even greater degree than the diminishment undergone by the first force. This will then set up a feedback cycle between the first and third forces that may in a short time overwhelm the second entirely. In this case, the second force could actually be said to have been fated for demolition by its own initial strength. Had it been weak at the outset a completely different scenario may have ensued, one that might have allowed it to dominate in the end. The point here is that conditions on the dynamical plane are very erratic, and mere position means far less *than the pathway by which one arrives there.*[17] Catastrophe theory specializes in accounting for these situations. It is interested in the effects of forces applied on a dynamical system from outside, forces that it then becomes the task of the system to neutralize, absorb, or resolve. As the resultant point begins to make its way across the plane (phase space), it will, according to the theory, encounter (nonlinear) regions where its behavior goes haywire, where gradual, continuous inputs produce sudden, discontinuous results. Here the system flips — a catastrophe — and gives rise to a whole new state or form.

It is the way in which catastrophe theory resolves or *embraces* conflict and difference that constitutes its radical opposition to hylomorphic theory. For catastrophe theory grants a certain reality to all virtual forces in a field, even those that have not been actualized, but remain enfolded until a singularity can draw them out. A form arises from something called a



15. Catastrophe surface showing control space, event space, fold, and its projection as a cusp (the catastrophe set). The plane below represents a Cartesian parameter space uninflected by any singularity. When a given trajectory is projected onto the space above it, both continuous and discontinuous behaviors become manifest. The fold represents an area of special interest and complexity because, for one thing, it is "bimodal," meaning that a single point in parameter space maps onto the fold twice, in two different modes (represented as upper and lower plateau).[18]

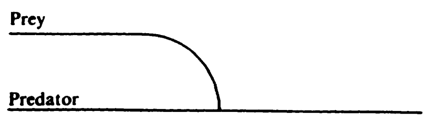
déploiement universel ("universal unfolding"), a dynamical pathway in which every virtuality is activated, even though only some get chosen.[19] Forms are always new and unpredictable unfoldings shaped by their adventures in time.[20] And, as we will see, only a fold offers the proper conditions to sustain another unfolding.

The idea that every object in the world can be associated with one or another dynamical system is not new; indeed, D'Arcy Thompson had already argued this back in 1917.[21] Yet a dynamical system is much more than a substrate space, it is in fact an "evental" complex. Now a catastrophe, as I have already suggested, can occur only in the region of a singularity. The regions on the plane (of parameter space) that give rise to catastrophes usually occupy but a small portion of the available space and they always have a regular and beautiful form. This form is what is known as the "catastrophe set" (the seven elementary catastrophes classified by René Thom).

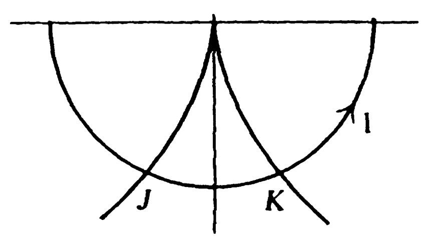
This form — the cusp, or catastrophe set — is a form indeed, yet it is of a slightly different nature than the forms discussed till now. Though the cusp fully belongs to the dynamical system, it is only a two-dimensional projection of the higher dimensional "event-form" unfolding as a catastrophe on the event surface above it. Here the catastrophe is actually a three-dimensional irruption on a two-dimensional surface (note that the action of folding is already a passage toward a higher dimension). What is interesting is that the catastrophe set always has the same form (geometrically) even though the catastrophe event-form (the specific unfolding) is unpredictable and open-ended. The catastrophe set is, in fact, an example of a *virtual form*.[22]

Virtual forms are real "folds" (not symbolic, not ideal) in real n-dimensional space that can give rise to indeterminate morphogenetic events in the n+1 space (the space one dimension higher up).[23] A genuine freedom and indeterminacy reigns in the n+1 event space (the catastrophe surface) where forms are actualized or unfolded, since the precise number, quality, and combination of real forces converging on the fold is quasi-random and unknowable in advance. Indeed, it is more truly the task of historians and theoreticians to reconstitute these after the fact than for science to predict them before they happen.[24]

Among the examples that Thom gives of geometrical entities that function like virtual or enfolded forms are his concepts of "charts" or "genetic forms."

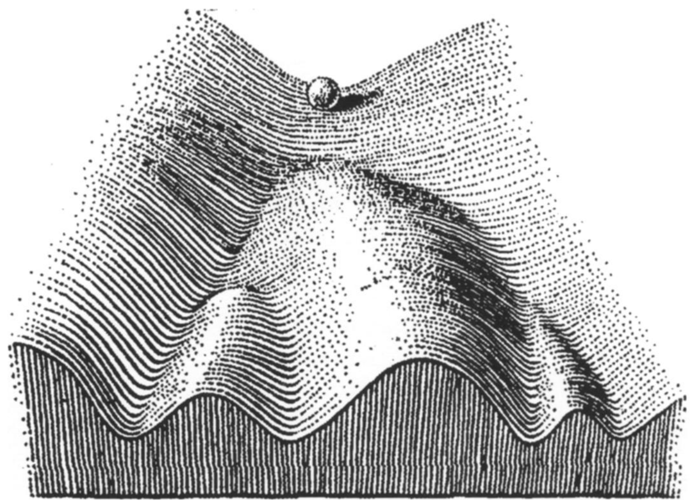


16. The capture morphology

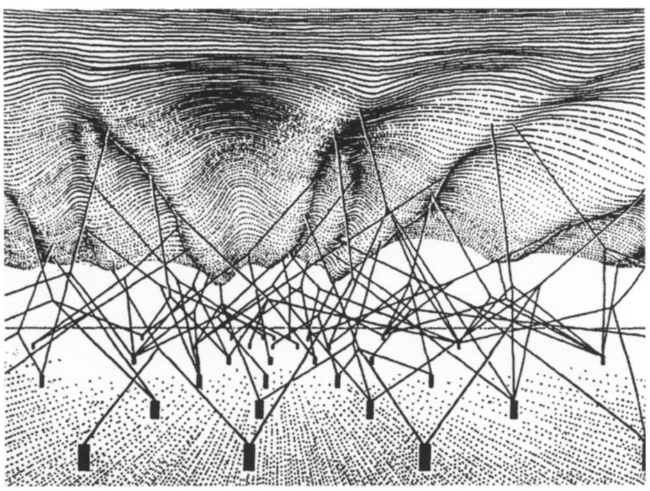


17. One half of a predation loop

These figures, such as the capture morphology illustrated here, are said to exist virtually somewhere in all biological beings, waiting to be unfolded in a variety of situations. These are, however, not at all fixed engrams, "but are defined dynamically, by a kind of never-ending embryology." The charts are triggered by so-called perception catastrophes — the sudden appearance, for example, of an object of prey in the visual or olfactory field of the predator (note that this event is already the projection of a fold embedded in another, contiguous space) — that is, by the sudden eruption of particular geometric configurations in the outside world that correspond to, and trigger, a virtual matrix within the animal. But the (predator-prey) loop need not be conceived as a correspondence phenomenon;[25] instead, it can be seen as a chance encounter of two flows on the same fold that causes their mutual, spontaneous geometricization and common unfolding into a single form: the "capture." The capture chreod — the moving template through which virtual forms are actualized — is once again the n-1 "space" that guides, but does not entirely determine, morphological events playing themselves out on another closely linked but higher dimensional surface.[26]



18. Epigenetic landscape seen from above. The evolution of a given form — represented by the ball's trajectory from a higher to a lower point — will likely join one of four pathways corresponding to the successive differentiations of the rivulets on the valley floor. Yet the introduction of any exogenous forces at any time in the system's evolution will perturb the ball from its determined trajectory and cause it to evolve a unique and original form. Thus the epigenetic landscape is far from deterministic: on the contrary, it actually absorbs and renders creative all contingency.



19. Epigenetic landscape seen from below. The complex relief features of the epigenetic surface are themselves largely the expression of a prodigiously complex network of interactions underlying it. The guy-ropes are tethered not only to random points on the overhead surface, but to points on other guy-ropes as well, and to pegs in the lower surface that themselves represent only semistabilized forms, thus multiplying exponentially the nonlinearities flowing through the system. Not to be diminished in importance either is the tension surface above as a distinct domain contributing its own forces to the field. No change in any single parameter can fail to be relayed throughout the system and to affect, in turn, conditions all across the event surface.

Among the most powerful geometrical concepts invented to depict the relation between phenomenal forms (phenotypes) and the morphogenetic fields in which they arise is Conrad Waddington's concept of the "epigenetic landscape." The epigenetic landscape is an undulating topographical surface in phase space (and therefore a descriptive model, not an explanatory device) whose multiplicity of valleys corresponds to the possible trajectories (shapes) of any body evolving (appearing) on it. [figure 18]

Assuming that there exists at all levels of nature a principle corresponding to the path of most economic action or least resistance (which is only a misguidedly negative expression of the deeper principle that every action is nonetheless accompanied by its own sufficient conditions), the rivulets and modulations of the epigenetic landscape correspond to built-in tendencies, or default scenarios, that would condition the evolution of forms in the hypothetical absence of supplementary forces acting over time. But one should not be fooled into taking the "form" of the epigenetic landscape as itself "essential," fixed, or predetermined. For it, too, is only a template, or virtual form, assembled *in another dimension*, as a multiplicity generated by an extremely complex field of forces. [figure 19]

Once time is introduced into this system, a form can gradually unfold on this surface *as a historically specific flow* of matter that actualizes (resolves, incarnates) the forces converging on the plane. These are the phenomenal forms that we conventionally associate with our lived world. What we have generally failed to understand about them is that they exist, enfolded in a virtual space, but are actualized (unfolded) only *in time* as a suite of morphological events and differentiations ever-carving themselves into the epigenetic landscape.

We would not be unjustified in saying, then, that in Boccioni's *Stati d'animo* series, what we find depicted are three evental complexes, or *three morphogenetic fields*, each arising within the same complex system of real matter and forces. Their startling morphological variety can be accounted for by the fact that each is triggered by a different singularity that, in turn, binds it to a specific attractor — *farewells*: turbulence, aggregation; *parting*: bifurcation, declension; *staying*: inertia, laminarity. The inchoate qualities of the form "fragments" that traditionally we are conditioned to see here are, in fact, nothing else than the manifest work of time plying the folds of matter to release the virtual forms within it. Each panel defines a unique field of unfolding, a section through a distinct epigenetic landscape in which forms exist only in evolution or equilibrium, that is, as event-generated *diagrams*, incarnating the multiple conflictual play of forces across all the dimensions of space and their modalities of convergence at a single specific instant in time.

Notes

I would like to express my gratitude to The Getty Center for the History of Art and the Humanities whose invitation to be a research fellow in the fall of 1990 provided the opportunity to undertake the research and writing of this essay.

1. Henri Bergson, *Matter and Memory*, trans. Nancy Margaret Paul and W. Scott Palmer (New York: Zone Books, 1988), 201.

2. Henri Bergson, *Creative Evolution*, trans. Arthur Mitchell (Lanham, Md.: University Press of America, 1983), chap. 2.

3. Henri Poincaré, "Sur le problème des trois corps et les équations de la dynamique," *Acta Mathematica* 13 (1890): 1–270, and idem, *Les Méthodes nouvelles de la mécanique celeste*, vols. 1–3 (Paris: Gauthiers-Villars, 1892–99). On the homoclinic functions that Poincaré discovered, compare Ivars Ekelund, *Le Calcul, l'imprévu* (Paris: Le Seuil, 1984), and Ralph Abraham and Chris Shaw, *Dynamics: The Geometry of Behavior*, vol. 3, *Global Behavior*, and vol. 4, *Bifurcation Behavior* (Santa Cruz: Ariel Press, 1986–88).

4. The biological sciences were the first to turn their attention to a systematic description of morphogenesis: entelechy theory (Driesch), gradient theory (Boveri, Child), embryonic fields (Gurwitsch), system-field theory (Weiss), topological deformation analysis (D'Arcy Thompson), Umwelt theory (von Uexküll), regulation theory. Finally, in England Joseph Needham, Conrad Waddington, and others created the Theoretical Biology Club to study developmental pathways in complex fields.

5. A combination of Christian neo-Platonism, eastern influences, and the eventual demise of Greco-Roman formalisms during the Middle Ages freed pictorial representation for centuries from its more static, analytic, spatializing tendencies. This partial emancipation from optical space introduced the modal (or musical) tendencies that we associate with the dynamic, surface-affirming, matter-organizing rather than space-projecting works of Byzantine and Romanesque art right up to the time of Duccio. Futurism's return to the *modal*, that is, to a space emphasizing both movement *and* "mosaic" qualities, does cubism one better by incorporating real, as opposed to derived or abstract, time into the modern work.

6. See my "La Città Nuova: Modernity and Continuity," in *ZONE* 1–2,

The Contemporary City, ed. Michel Feher and Sanford Kwinter (New York: Zone Books, 1986).

7. An important systematic critique of hylomorphism can be found in Gilbert Simondon, *L'Individu et sa génèse physico-biologique* (Paris: PUF, 1964). See also Joseph Needham, "Matter, Form, Evolution and Us," *This Changing World* 6 (1944).

8. The grid system, just like the so-called Western metaphysics upon which it is based, can be neither subverted nor deconstructed from within, despite the claims of practitioners who imagine they have introduced their own little cracks into it. The only "weak forms" that we know of are those weak forms of thought that, unable to resingularize a homogenous, quantitative space, console themselves by attacking it resentfully. Far more interesting is the dishomogenizing act of mathematician René Thom, who sees in even the hyperrational, quasi-featureless Cartesian plane the appearance of irreducible morphological qualities: in the case at hand, a so-called capture chreod in a predation loop (a point being swallowed by the *x* and *y* axes as they scissor around it). See René Thom, *Structural Stability and Morphogenesis* (Reading, Mass.: Addison-Wesley, 1975), 314–15.

9. I am following Bergson's distinction between qualitative, intensive multiplicities and quantitative, extensive ones. The former are defined as those that cannot be divided without changing in *nature*. This is because they possess creative inhomogeneities — their *intensive* nature follows from the fact that they are distributed in time (and therefore unequally, cumulatively, dynamically) not space — and because they are *virtual* and proceed by continuous actualization/differentiation, not repetition/representation.

10. Hassler Whitney, "On Singularities of Mappings of Euclidean Spaces: I. Mappings of the Plane onto the Plane," *Annals of Mathematics* 62 (1955). Whitney is the inventor of singularity theory and the true father of catastrophe theory.

11. The perplexing results of recent cold fusion experiments suggest that one is on the verge of isolating a new singularity of water (this may not be cold fusion but it is almost certainly something else). How much of human history could be written from the perspective of how cultures organized themselves around the singularities of materials in general, and water in particular (the hydraulic cultures of the Middle Ages, the fundamental role of steam pressure in nineteenth-century industrialism, etc.)? The question is always: Which singularities have crossed the defining threshold of human technics and which have not?

12. The terms *system* and *space* had become indistinguishable, I would argue, already in the work of Ludwig Boltzmann, who in the 1870s invented an entirely new type of space known as "phase space." Phase space is a multidimensional space whose coordinates no longer represent "places" but rather (possible) *states* of a system. The coordinates represent independent variables that characterize a real system at any given moment, such as its temperature, pressure, speed, direction, and all the possible combinations of these. As a given system evolves through time, it carves out a precise figure in phase space, forming, as it were, its behavior portrait. It is this dynamical, virtual form, unavailable either to brute perception or algebraic or classical Euclidean expression, that is the *propos* of the present article.

13. Potential theory is in many ways the precursor of phase space and represents a crucial episode in the dynamicization of the classical coordinate grid. J.-L. Lagrange reformulated dynamics in the late eighteenth century when he introduced the theory of the conservation of energy. Each point on the grid came to represent a certain amount of available energy, or potential to change or move to another state. A few decades later William Rowan Hamilton added *momentum coordinates* (velocity times mass) to Lagrange's *potential coordinates*, allowing one to plot the system's total energy as a single quantity on the Cartesian plane. Seen in retrospect, it was but a short further step to the nineteenth century's probability theory and Boltzmann's statistical mechanics.

14. Sometimes quantum, atomic, or molecular level phenomena manifest themselves globally as in laser-phase locking, Bénard convection patterns, or percolation transitions. At the biological level dictyostelium amoebas, termite larvae, and neural networks are three very commonly studied examples of spontaneously self-organizing systems.

15. M. V. Berry, "Regular and Irregular Motion," in *Topics in Non-Linear Dynamics*, ed. Siebe Jorna (New York: American Institute of Physics, 1978), 16–120.

16. See *Structural Stability and Morphogenesis*, chaps. 9–11, for René Thom's exhilirating but exceedingly bizarre demonstrations of the mathematics of organogenesis. The chapter that develops the dynamical theory of genital "chreods" carries the epigraph "And the word was made flesh" from the Gospels according to Saint John. Because there has been an almost systematic mistreatment of these and related ideas within architectural circles it is perhaps appropriate to register the following caveat: French catastrophe theory — that of Thom and certain of his American followers — is different, and to my mind far richer, than the apparently more accessible, and well-publicized, catastrophe theory of the English School — that of Christopher Zeeman and others at the University of Warwick and elsewhere. The former is primarily a philosophical, theoretical enterprise, indeed, an "art of models" applicable to natural phenomena in general through an intuitive and descriptive geometrical-mathematical method. The latter, however, often called "applied" catastrophe theory, has recourse, all too often, to simplistic and insufficiently conceptualized models; it is far more obsessed with predictive accuracy and quantitative verification, criteria that arguably are partly inappropriate and partly premature though perhaps necessary for the evangelism with which they disseminate the theory in popular and scientific circles. English catastrophe theory has, as a result, often overstated its case and suffered many sterile ventures and withering criticisms, while the importance and suggestiveness of Thom's work continues to increase exponentially.

17. Trajectories in state or phase space are *developmental or evolutionary pathways* that describe the transformative action of time on a system; they are no longer simply "forms in space" in the classical (reductionist, metaphysical) sense.

In this respect, the "history" of a system takes on an importance unprecedented in scientific method.

18. Clearly real objects are constituted in n-dimensional parameter space and inhabit folds so complex that their modality factor may be represented as n-1. For an explanation of this relation, see the ensuing discussion.

19. *Evocation* is another word often used here (as in biochemical evocators during embryological development) to describe the simultaneous emergence at certain critical moments within a morphogenetic field of not one, but a variety of new regimes. See Thom, *Structural Stability and Morphogenesis*, 31–34, 95–96; idem, *Modèles mathématiques de la morphogénèse* (Paris: Bourgois, 1981), chap. 3; and idem, *Paraboles et catastrophes* (Paris: Flammarion, 1983), 27–28.

20. This extremely interesting and complex aspect of dynamics cannot be dealt with here. I have developed some aspects of enfoldedness and virtuality in my "Drawing as Eros and Memory," *Steel Notes* (National Gallery of Canada, 1988) and will treat the problem of "virtuality" in depth in a forthcoming study of formalism.

21. We owe to D'Arcy Thompson the original insight that genetic program can contribute nothing more than internal constraints on the evolution of a system or form, that much still depends on what accidental (exogenous) forces are deployed with it to actualize or unfold the individual. See D'Arcy Thompson, *On Growth and Form* (Cambridge: Cambridge University Press, 1961). See also idem, "On the Shapes of Eggs and the Causes Which Determine Them," *Nature* 78 (1908): lll. In this same vein, Thom himself has gone as far as to pronounce his own work to be a type of "neo-Lamarckism." See Thom, *Structural Stability and Morphogenesis*, 205, 281, 293, and idem, *Paraboles et catastrophes*, 44–45.

22. For Thom, however, the elementary catastrophes are, on the contrary, pregiven Platonic forms that somehow determine all morphogenesis in the universe, from the breaking of waves in the ocean (hyperbolic umbilic) to the formation of fingers on the hand (elliptical umbilic). But this formulation seems naïve and incommensurate with Thom's other, generally more nuanced positions. Preferable here is Waddington's notion of "homeorhesis," which describes the principle by which inexact morphogenetic trajectories, or moving templates, guide the evolution of forms. Waddington's equations describing *nonlinearity* in embryonic development are among the clearest and most accessible to the lay reader. See Conrad H. Waddington, *The Strategy of the Genes* (New York: Macmillan, 1957), 16–22.

23. Clearly, the present study does not even attempt to exhaust the immense and peculiar morphodynamic power of the fold. It describes only its *exfoliative* properties, leaving to one side entirely its *involutionary* dynamics, such as those found in the infinite but bounded morphology of the chaotic attractor and the stretch/fold dynamics of mixing.

24. Between James Clerk Maxwell and Poincaré (and omitting for the moment Boltzmann's important contribution) the whole determinacy problem became one of the great watersheds of late-nineteenth-century epistemology. For Maxwell, the impossibility of achieving absolute exactitude in the description of physical systems would always give instabilities the upper hand and introduce unpredictability into the system. Indeed, Maxwell claimed that no event ever occured twice. Poincaré added to this a mathematical proof demonstrating that even impossible events must recur infinitely. Classical quantitative methods had simply reached a dead end in their attempt to provide a rigorous description of events unfolding over time. These historical developments cleared the way for the return of geometry (qualitative methods) as a mode of explanation. See "Does the Progress of Physical Science Tend to Give any Advantage to the Opinion of Necessity (or Determinism) over that of Events and the Freedom of the Will?" in L. Campbell and W. Garret, *The Life of James Clerk Maxwell* (London: Macmillan, 1882), and Poincaré, *Méthodes nouvelles*, vol. 1.

25. This does, however, seem to be the way Thom seeks to understand it. An alternate, and perhaps richer, general model may be derived from the "enactionist" theories of U. Maturana and F. Varela, *Autopoiesis and Cognition: The Realization of the Living* (Dordrecht: Reidel, 1980).

26. The term *chreod* is Waddington's coinage, from the Greek *khre* "necessary" or "determined" and *hodos* "route" or "pathway."

Figure Credits

1. *The Futurist Imagination: Word + Image in Italian Futurist Painting, Drawing, Collage, and Free-Word Poetry*, ed. Anne Coffin Hanson (New Haven: Yale University Art Gallery, 1983).

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3, 10. S. Chandrasekhar, *Principles of Stellar Dynamics* (New York: Dover, 1960).

4, 13. W. H. Bascom, *Waves and Beaches* (New York: Doubleday, 1974).

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7. Dr. Elena Budrene, Harvard University.

9. E. Sherbon Hills, *Elements of Structural Geology* (New York: Methuen, 1963).

11. Alan Garfinkel, "The Slime Mold Dictyostelium as a Model of Self-Organization in Social Systems," in *Self-Organizing Systems*, ed. Eugene Yates (New York: Plenum Press, 1987). Redrawn by Joseph MacDonald.

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16, 17. René Thom, *Structural Stability and Morphogenesis* (Reading, Mass.: Addison-Wesley, 1975).

18, 19. Conrad H. Waddington, *Strategy of the Genes* (New York: Macmillan, 1957).