Pierre Gilles de Gennes

CHANCE AND NECESSITY IN COOPERATIVE PHENOMENA

I. GENERAL CHARACTERISTICS OF COOPERATIVITY

I.1 *Magnets and Fish*

A lone fish swims haphazardly in any direction, but if we get enough fish of the same species together so that neighboring individual fish may exchange signals, they adopt a common direction. Here we have a phenomenon of cooperation: many individuals find themselves in strong interaction with each other, and overall behavior is noticeably affected.[1]

The physical sciences offer us a large variety of such phenomena. For example, inside an iron crystal we find a small microscopic compass on each atom, the "moment" of the iron atom. All these moments are connected, and at a temperature which is not too high they all point in the same direction: the metal is then said to be *ferromagnetic*.[2]

Some researchers quickly seized on the idea that a strong

Translated by Jeanne Ferguson.

[1] Callen and Shapero, *Physics Today*, July, 1974, p. 23.
[2] N. Boccara, *La physique des transitions*, Coll. "Que sais-je?," P.U.F., 1970.

https://doi.org/10.1177/039219217702510011 Published online by Cambridge University Press

link exists between quite different cooperative phenomena, whether it was a question of magnets, fish or human societies (which for example show vascillation in opinions).[3] The analogy is tempting, but ticklish; some obvious differences must be immediately pointed out:

a) Elementary objects in physics or chemistry (for example, individual magnets) are relatively simple and wellknown. When the "elementary object" is a living organism, if we are to describe it in the same terms we must proceed to a dangerous *reduction*: we must sum up its behavior in a certain number of carefully-chosen quantitative parameters;

b) Structures met with in the natural sciences are much more primitive than those found in the social sciences. On the other hand they may well serve as the subjects of *active* experimentation in which a natural system is subjected to various disturbances, each of which may be observed by us;

c) the natural sciences are relatively mature, and their methodology has reached a certain stability. Their researchers have a wide experience in the construction of *"minimal" quantitative models*, those which give the pertinent aspects of the phenomenon.

The younger sciences, on the other hand, go through successive and opposed phases: qualitative theories, overmathematization (especially now that there are computers).

The aim of this article is to present some basic concepts which have emerged from the study of the simplest cooperative physical-chemical phenomena, with the hope that some of these ideas may prove useful for social phenomena.

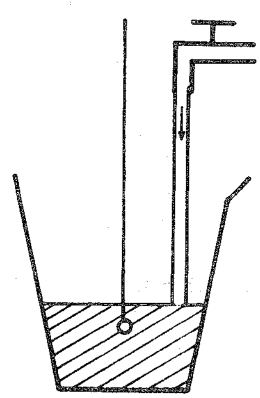
We will go even further: beginning with different physical situations, we will suggest possible transpositions toward social problems. These attempts will be made from the "outside" with no reference to the sociological literature (with which the present author is far from being well-acquainted). They make no claim to novelty: even inside the physical sciences the concepts described herein have often been found by different researchers using different examples.

[3] Weidlich, "Dynamics of Interacting Social Groups," *Progress in Synergetics*, North Holland, H. Haken, ed., 1974.

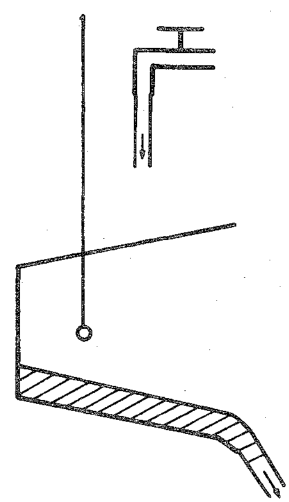
https://doi.org/10.1177/039219217702510011 Published online by Cambridge University Press

I.2 *Closed Systems and Open Systems*

Certain physical settings insure that the studied system may achieve a permanent equilibrium within an enclosure (for example, a container with a *uniform* temperature). Others keep the system out of balance by its being enclosed in a container two sides of which are of *different* temperatures. In the first case we speak of a *closed* system. In the second case, on the contrary, a certain flux crosses the container (a flow of heat goes from the warm side to the cold side), whence the term *open* system. This distinction is fundamental: closed systems evolve toward an equilibrium following relatively simple laws and only later deviate from it because of weakening fluctuations. Open systems are much more versatile. Fig. 1 well illustrates the possibilities for open systems. The bucket is continually fed by a faucet. When there is little water in the bucket it is in the "a" state and fills. But when the water rises above a certain level (the "b" state) it tips, empties and returns to "a." Here we have an "oscillation of relaxation"



a) Filling



b) Spontaneous emptying

(Fig. 1)

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which is indefinitely repeated and is typical of certain open systems.

We will first consider closed systems, and we will show, following Weidlich,[4] that they may have not negligible social counterparts. Then we will consider open systems, whose importance is fairly well admitted at present.[5] For all socio-economic (or ecological, or biological) cases in which a flow (of energy, of raw material) enters the system at the same time as a flow (of heat, of waste) leaves it, we may think in terms of an open system.

I.3 *Symmetries and broken symmetries*[6]

It often happens that the behavioral laws of a system under observation will obey certain *symmetries*, for example, a school of fish:

a) In the absence of any external stimulus, the speed of movement of a single fish from one place to another does not depend on the direction he has chosen (north, or east) on a horizontal plane;

b) the grouping of fish is also independent of the overall direction of movement.

Then we say that the school is grouped in a symmetry G_o (here indicating the set of rotations around a vertical axis).

Similarly, let us now consider a group of elementary magnets, as in iron, and let us suppose that each magnet has only two possible positions: pointing upward or pointing downward:

a) a single magnet, in the absence of any external disturbance, may point either upward or downward;

b) the energy of coupling between two "upward-pointing" magnets is equal to that of two "downward-pointing" magnets.

[4] Weidlich, *British Journal of Mathematics and Statistical Psychology*, 1971, *24*, p. 251.

[5] I. Prigogine, P. Glansdorff, *Thermodynamic Theory of Structure, Stability and Fluctuations*, Wiley, 1971. Cf. also J. De Rosnay, *Le Macroscope*, Ed. Seuil, 1975.

[6] Cf. N. Boccara, *Symétries brisées et transitions de phase*, Hermann, 1975.

The essential observation is then the following: if the system organizes itself as a result of a cooperative phenomenon, it spontaneously adopts a state which has *lost* the G_o symmetry. And so also with fish: if the coupling between them is weak, each will take off haphazardly on its own with no common direction: the symmetry of rotation is respected. But if the coupling is strong the fish will line up side by side and choose a common direction of movement. If we make calculations on such a school (by sonar, for example) we will find an anisotropic behavior: the symmetry G_o is broken.

There are in fact two ways to break the G_o symmetry:

i) by external means (for example, putting food in a certain direction near the school);

ii) spontaneously: if we start from a given situation and the grouping is suddenly reinforced (by making the water more transparent so that it is easier for the fish to exchange signals) the school chooses *one* direction, haphazardly. Or more precisely, it proceeds by an *amplification in fluctuation.* If at the beginning there were a few too many fish (with respect to the average) going north-east, the entire school will head toward the north-east. Here we see an important association of chance with necessity: a common action *must* occur, but the choice of the action is left to chance.

This concept is of course found again in magnets: in an ordered state they tend to line up and point upward. At this moment the upward/downward symmetry is broken.

I.4 *A Link with Curie's Principle*

About a hundred years ago Pierre Curie expressed a very general principle concerning the structure of physical laws:[7] "The symmetry of effects is the same as the symmetry of causes." This principle is important and almost always correct. But it is violated when a spontaneous rupture of symmetry occurs: at the moment of the rupture there is the possibility of several final states, and the system chooses only one of them. Curie's principle only has meaning when the final state (which defines the "effects") is unique.

[7] Pierre Curie, *Journal de physique*, Sept., 1894, p. 393.

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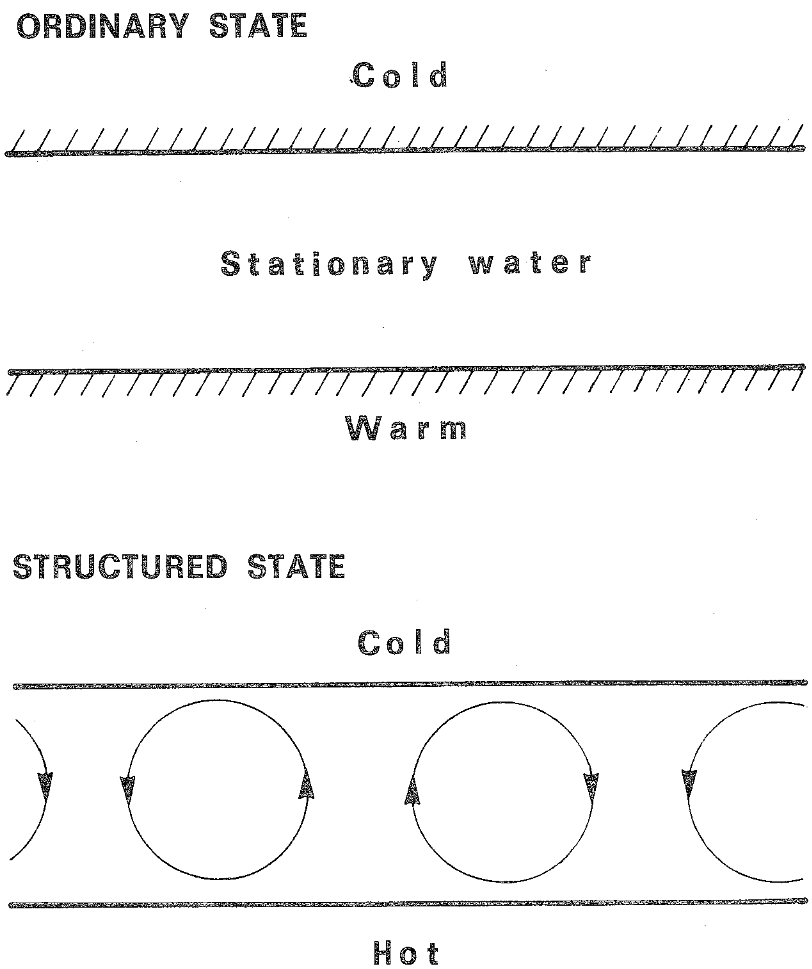
I.5 Rupture of Symmetry in Open Systems

The example of magnets given above corresponds to a closed system. But it is important to realize that spontaneous ruptures are also frequent in an *open* system. Thus, when we heat a thin sheet of water from underneath we see above a



(Fig. 2)

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certain threshold an instability (Bénard's instability) which is due to the fact that warm water, being lighter in weight, tends to rise. This is an example of an open system (traversed by a flow of heat). And there is a definite rupture of symmetry, as Fig. 2 shows.

On this side of the threshold the water has a "translational symmetry": if we move along the axis xx' we find the same properties everywhere. On the other side of the threshold, this symmetry is broken: "eddies of convection" appear.

Here we have a very simple example of *structuration in an open system.* The underlying qualitative description for sciences other than the natural is found in a work by R. Caillois.[8] The importance and the general application of this process (for example, the formal discussion of the origin of life) was very early appreciated by I. Prigogine.[9]

I.6 *Discrete Symmetries and Continuous Symmetries*

In mathematical language, there may be two groups of G_o symmetry: "discrete" and "continuous." Without going into detail on this definition, we point out that it is linked to the number of accessible states after a rupture of symmetry: for our magnets, there are only two, upward and downward. On the other hand, there are an infinite number of possible directions for a school of fish to take—all the angles of a marine compass. The first case is discrete, the second continuous.

This geometrical difference may appear very formal: it is essential however when more complex situations claim our attention, for example, the *encounter between two schools of fish.* In the situations of a discrete G_o a well-defined *frontier* will exist between two differing spheres. In situations of a continuous G_o there is no frontier but there are progressively more distortions and at times formation of *lines* or single *points.*[10]

[8] R. Caillois, *Symétrie et dissymétrie*, N.R.F.
[9] I. Prigogine, *op. cit.*
[10] M. Kleman, "Points lignes parois," Editions de Physique, 1977.

II. COOPERATIVE EFFECTS IN EQUILIBRIUM

A closed physical system evolves toward an equilibrium and at that moment has a rather trivial behavior. However, as we have seen, things change if more than one state of equilibrium is possible—if the system "hesitates" before choosing one of several states. We will now see how this hesitation may appear at a critical point, when we vary certain control parameters.

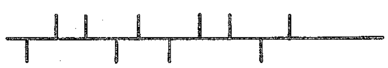
II.1 *The Concept of a Critical Point*

At high temperature the elementary magnets in an iron crystal are in a totally unorganized state. There is no privileged orientation. On the other hand, below a certain critical temperature—T_c—the magnets become orderly; most of them will point in the same direction. There are some which go against the current, but the lower the temperature the stricter the ordering, as is shown in the following schemas:

a) T greater than T_c:

50% pointing upward
50% pointing downward

b) T slightly less than T_c:



60% pointing upward
40% pointing downward

c) T very much less than T_c:

90% pointing upward
10% pointing downward

(Fig. 3)

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To illustrate the mechanism involved, we propose another—though conjectural—example based on the social behavior of young children in a nursery. Below a certain critical age (around two and a half) they exchange signals and play, but the games are not coordinated. On the contrary, when the critical age has passed, a significant fraction of the group tends to take part in the same game. Let us start from the hypothesis that the relationship magnets ⟷ children makes sense. What will we then draw from our experience with magnetic systems? First, it will suggest the extraction of two essential parameters:

a) strength of *coupling* between individuals;

b) an *individual susceptibility* which measures the aptitude of a subject to respond to external signals. (In the case of magnets this susceptibility decreases when the temperature rises.)

When the product (coupling x susceptibility) is above a certain level, behavior becomes cooperative: we pass through a critical point. It would be interesting to know if these concepts have been (or can be) applied to the question of the social behavior of young children.

II.2 *Response Functions* [11]

We introduced *individual* susceptibility above. Another important quantity is *collective* susceptibility, which measures the response of an individual when the system is subjected to a common external action: a "magnetic field" for our little magnets or a loudspeaker pouring out music for the children in the nursery. Collective susceptibility may be *much greater* than individual susceptibility: each child receives not only the sound from the loudspeaker, but he sees his neighbors clapping their hands, etc.

At the critical point, the collective susceptibility becomes infinite; the laws which govern this anomaly are known. Whence a possibility to *see in advance the approach of a critical point*, for example by measuring the collective susceptibility of children a little below the critical age.

[11] N. Boccara, *Symétries brisées et transitions de phase,* Hermann, 1975.

Collective susceptibility is an example of the more general concept of the response functions—important in all statistical systems. Further on we will give other examples.

II.3 *Spontaneous Fluctuations and Response Functions* [12]

Let us return to the system of coupled magnets and let us assume the temperature to be above the critical point T_c. Under these conditions there are, on the average, 50% of the magnets pointing upward and 50% pointing downward. But there are of course fluctuations with respect to this average. A large segment of closed systems then obeys a convenient theorem: *the intensity of the fluctuation is in proportion to collective susceptibility.* Particularly, as the critical point is approached, fluctuations become very important, and this brings up another method of inquiry on this point.

II.4 *Vicinal Systems*

In many cases, the physical system in which cooperative phenomena may be observed are *solids,* wherein the constituent atoms are either arranged in perfect order (crystals) or in a certain disorder (glass).

Under these conditions, an entire series of questions arises connected with the *spatial* correlation between individuals: the most important developments in statistical mechanics in the last ten years have been specifically directed to this type of question. The situation which we have just described corresponds on the sociological level to a collection of individuals occupying fixed positions and exchanging information only with their nearest neighbors—what we call a vicinal system. In such a system, individuals may still be subjected to the influence of mass media, which plays an analogous role to that of the external field for magnetic compasses. On the other hand, there is no direct, binary interaction between two individuals who are distant from each other.

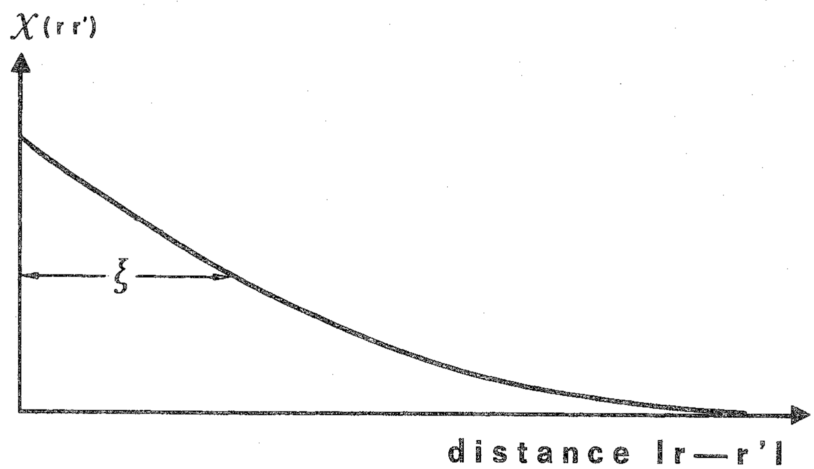
This restriction, which corresponds to the normal laws for condensed matter in physics, seems more limiting in sociology;

[12] *Ibid.*

at least in contemporary society, a lively, close contact between individuals has a considerable effect. It is no doubt true that a subject interacts mostly with a limited number of people, but these (colleagues at work, for example) may live quite far from him: spatial rapports are less constraining in a city than they are in a crystal.

For this reason, we will not stress the spatial properties of vicinal systems and will only present two basic concepts which are associated with them: a non-local response function and the degree of correlation.

The *non-local response function* is defined by the following operation: a weak external disturbance is applied to an individual located at point "r." Other individuals feel absolutely no external disturbance. But "r" changes his behavior and reacts upon his neighbors. These in turn change their behavior and on the one hand influence "r," while on the other they influence more distant neighbors. Finally, we may measure a change in behavior in an individual who is quite far away (located at a certain point "r'"). This change is in proportion to the strength of the disturbance at "r": the ratio defines the non-local susceptibility X(rr'). Most often X(rr') decreases when the observation point "r'" withdraws from the point of attack "r" (Fig. 4).



(Fig. 4)

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In most cases—at least in the *disordered* phase: in the ordered phase, if the group G_o is continuous, the rate of decrease is very slow—the X function becomes negligible beyond a certain characteristic point ξ, the *degree of correlation.*

In a very disordered situation the degree of correlation is weak (comparable to the distance between neighbors.) But if we approach the critical point, the degree (of length) ξ increases greatly and diverges toward $T = T_c$. It has taken fifty years to understand well the mathematical laws which govern this divergence, but now the situation is under control.[13]

Note: In all the above discussion, we have assumed that connections between neighbors were actually present. In the case where certain ties between neighbors are *cut* and communication is seriously reduced, a phenomenon of *percolation* is involved, for which we refer the reader to another article.[14]

III. SCHEMES OF TEMPORAL EVOLUTION

III.1 *Weak Disturbances in the Vicinity of an Equilibrium*

The system (or the population) we are observing is almost always subjected to external influence: a school of fish receives a variety of stimuli (directional, lighting, gradients in temperature and salinity, etc.) Up until now we have discussed only the response to a weak and permanent stimulus. In the presence of such a stimulus the system ends by reaching an internal equilibrium.

Two generalized axes appear:

a) cases of stimuli which are weak vary in time;
b) cases of strong disturbance and resultant instability.

Here we will briefly discuss the first case. The basic tool for analyzing these situations is the concept of a *delayed response function*: a disturbance of brief duration occurs at the moment t_1, and the response is measured at a later time t_2.

[13] *Ibid.*
[14] P. G. De Gennes, *La Recherche*, 1976, 7, p. 919.

The response function defined in this way X (t_1 t_2) gives precious information on the internal dynamics of the system. Let us mention here as an example the fact that the responses become very slow when we near a critical point.

III.2 *Two Kinds of Instability*

All usual systems may be rendered unstable:

i) a closed system of coupled magnets becomes unstable if there is an influence opposed to the orientation the system has chosen;

ii) an open system traversed by a violent flux is often unstable: so it is for the sheet of water heated from beneath and illustrated in Fig. 2. We see how it passes from an ordinary state (O) to a structured state (S).

Instabilities can appear in many different forms: the "theory of catastrophes"[15] gives us a certain geometric classification for them. For our purposes in this article, we must make a fundamental distinction between two types of instability:

— instability of fluctuation: even a slight split with relation to the O state will inexorably widen in time and cause the evolution of the system from O to S (a cause met in the sheet of water);

— instability of *nucleation*: system O remains stable with respect to weak fluctuations but becomes unstable for certain strong fluctuations.

We are going to illustrate these rather austere concepts by some concrete examples.

III.3 *Two Instabilities of Fluctuation: Laser and Fads*

A laser is an enclosure in which we find grains of light (photons) P and atoms (A*) excited by an annexed device.

[15] R. Thom, *Stabilité structurelle et morphogénèse*, New York, Benjamin, 1972. For its application in sociology, see C. Isnard and E. Zeeman in *Use of Models in the Social Sciences*, ed. by L. Collins, London, Tavistock, 1974.

In essence the process is as follows: a photon (P) arriving at an atom (A^*) may de-excite it ($A^* \rightarrow A$) and cause the formation of a second photon P':

$$P + A^* \rightarrow P + P' + A$$

This mechanism (anticipated by Einstein) constitutes what is called a *stimulated emission*. It may lead to an instability in fluctuation: the stimulated emission increases the number of photons, all the more so because this number is already large. Of course, the process has to compete with certain losses (absorption of photons): instability occurs only when the fraction of excited atoms A is sufficiently large. Then fluctuations in the number of photons increase. There is competition between the different possible types of photons: the "type" that increases the most is victorious and installs itself in the laser cavity as a particularly pure, "coherent" beam.

It took a long time to pass from stimulated emission to laser, but at present this kind of cooperative instability is found in extremely varied branches of science. For a reader who does not fear the formalism of the natural sciences, the book by Haken[16] will be of great help. The process of the evolution of a living species (a virus) subjected to accidental mutations and to the pressure of Darwinian selection is governed by equations somewhat analogous to those of the laser.[17]

Here we will give a slightly different example: that of fads. A new style abruptly and unexpectedly appears: this is indeed a cooperative instability, putting several systems into play (consumers, producers) brought together by the media. We will choose here a relatively simple case in which only an elementary phenomenon figures, one I will call the *Fontanges Instability*. Finding herself in a park on a windy day, Mlle. de Fontanges, nearly strangled by her long hair, chanced to tie it back with a ribbon. The next day all the elegant women of the court imitated her. This example was perhaps distorted because of the king's favor. I nonetheless retain it, because

[16] H. Haken, *Introduction to Synergetics*, Springer, 1976.
[17] M. Eigen, *Quarterly Review of Biophyscs*, 1971, *4*, p. 149.

it describes a case in which the appearance of a new fashion was not complicated by problems of supply (ribbons are easy to come by), production or price.

The process is as follows: we start from a stationary collectivity in which a certain number of hair styles are adopted and acceptable. Then comes a statistical fluctuation: a subject (Mlle. de Fontanges) finds itself in an abnormal situation. This "abnormal" P meets a spectator A*, who is surprised and charmed by the irregularity. After a very short time (time enough to return to her mirror) the spectator changes into an actor and adopts the P state:

$$P + A^* \rightarrow P + P$$

The mechanism follows its course, each newly-created P creating in turn new actors. The analogy with stimulated emission is striking. Here also, of course, there are dissipative mechanisms which fight against instability (the acid comments of the dowagers cause some timid young ladies to retreat). But if the initial conditions are right, if the court is mentally disposed at that moment, (an analogy with the number of excited atoms in a laser cavity) the instability will take place.

There is much to say about the later evolution, the different time scales involved, the role played by the means of production and the media, evolution coupled with these different subsystems. But one question remains particularly open: do we, like laser, have final states in fashion which all differ because of their rate of increase, so that the system necessarily chooses the one whose growth rate is the most rapid? Or have we a situation in which a number of possible final states have the same rate of initial growth?

If we are in the second case, a *second cooperative effect* is required in order to understand the fact that, most often, only one fashion is chosen. This second effect may be psycho-sociological (mutual support among the "abnormals" of the same type) or economic (launching of the means of production in only one direction). So many ways to explore.

III.4 *Phenomena of Nucleation and Voters' Attitudes*

To illustrate the effects of nucleation, let us first return to a group of coupled magnets (below its critical point) and let us suppose that they are oriented "downward" (here we explicitly choose a vicinal system with, in addition, a *discrete* G_o group). Now let us suppose that an external influence is applied to the magnets and that it tends to orient them "upward": the initial situation has become unstable, but how will the change be made?

The system begins by creating a "germ," that is, a group of neighboring magnets oriented in the right direction (upward). The spontaneous fluctuations in the system—always present—permit it to create such a germ. But its future is not certain: if it is too small, the influence of its surroundings will most often force it to regress. In order to triumph over its surroundings, it must have already reached a certain critical size. But the fluctuations which create a germ of this size are rare.

On the whole, if the external force is weak, the time required for the gestation of an efficacious germ is long: the corresponding quantitative laws are known.[18] But there is a complication: the formation of germs is very sensitive to local heterogeneities, that is, to small groups whose behavior is at some distance from the average. The process of nucleation is a *revealer of the defects of the initial structure.*

Also to be noted: nucleation, as it has just been described, only exists for systems in which the broken symmetry group G_o is discrete. For systems with continuous G_o there are more efficient means for the propagating of instability, since there is no longer a distinct wall between a germ and its environment. These theorems may be more easily perceived through the example of an election:

a) In a presidential election with *two* candidates, X and Y, each voter has three possibilities—X, Y, or abstention: G_o is discrete. Nucleation may occur if at the beginning the voters make up a cooperative majority (through mutual support) in favor of X, but the media launches a campaign in favor of Y.

[18] *Nucleation*, ed. A. Zettlomayer, M. Dekker, New York, 1969.

If the system is vicinal, the process of slow nucleation described above may occur, and the majority will switch to Y.

b) A counter-example: for an election in which a large number of candidates participate, with a wide and almost continuous spectrum of opinions, group G_o is continuous. If, in this case, the media launches a "counter-campaign" (with respect to the initial cooperative attitude of the electoral body) we find an instability of fluctuation involving a large fraction of the voters, and not a nucleation.

III.5 *Post-Instability Situations*

Here let us consider an open system subjected to more and more powerful fluxes, for example, the sheet of water described earlier which is heated from beneath. In this particular case the sequence of events encountered at an increasing temperature is incredibly complex: we are far from understanding it. We may nevertheless give a rather precise classification of the regimes (in an increasing flux):

a) a banal stationary regime after the initial instability;

b) a structured stationary regime after the initial instability (see Fig. 2);

c) after a time, the appearance of oscillating phenomena (see Fig. 1);

d) *chaos*, a state in which the system is in constant evolution, so that no definite periodicity can be observed.

For flowing liquids chaos corresponds to what is called *turbulence*: the type of strange and unpredictable agitation which is seen behind bridge piers. For the moment turbulence is not understood, but there are simpler examples of chaotic situations.

The most striking is undoubtedly that of the problem of *annual production* as it is formulated in elementary works on economics. Let Q_n be the quantity of artichokes produced by such and such a grower for the year "n." When the moment arrives to decide on the volume of production for "n," the most important available information is the profit or loss occurring the preceding year (n-1). This profit was itself a func-

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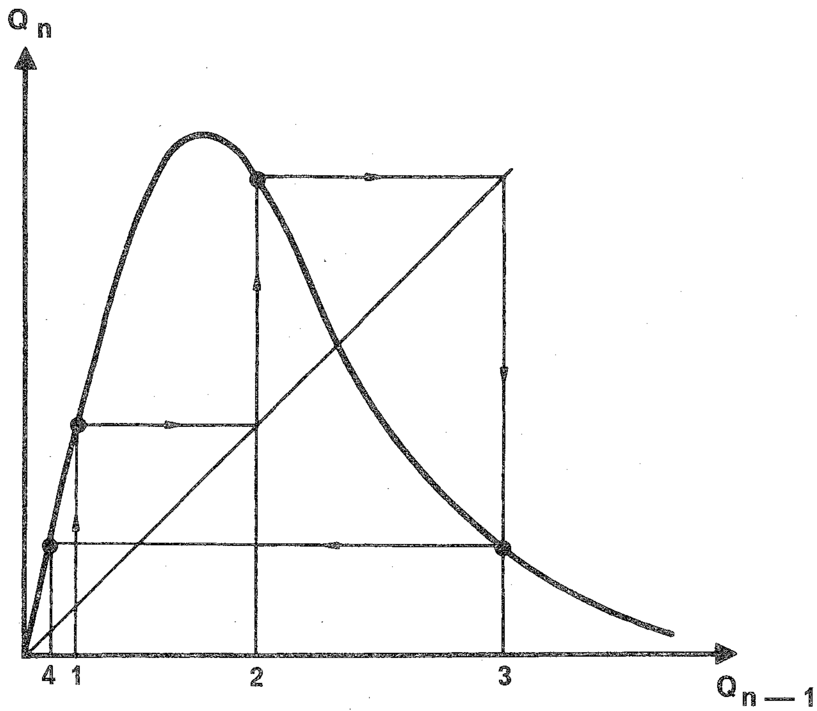
tion of the quantity Q_{n-1}: Usually the most primitive pattern describing the adjustment of production assumes that Q_n depends only on Q_{n-1}.

For a small Q_{n-1} there is the ratio $Q_n = \alpha Q_{n-1}$. But for a large Q_{n-1} prices have fallen and the growers react by limiting their production, thus the curve again falls (Fig. 5).



(Fig. 5)

It is amusing to see that this pattern, long known, has only recently been really understood (through studies at Princeton on the biology of populations).[19] There are a number of regimes according to the value of the "initial slope" α:

[19] R. M. May, *Journal of Theoretical Biology*, 1975, 49.

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a) for $\alpha < 1$, production slows down and tends toward zero;

b) for α slightly larger than 1, the Q_n quantities tend toward a fixed point: there is a stable regime of production;

c) for a slightly larger α the system tends to *oscillate* (annually or biennially, according to the value of α);

d) finally, for a very large α we find chaos: the Q_n quantities vary with the year in an apparently *erratic* manner. This is the point which escaped an entire generation of economists.

The four regimes given above may be easily perceived by means of the graphic constructions on the curve Q_n, Q_{n-1} or by the use of a pocket computer, by calculating the sequence of the Q_n. The chaotic behavior is particularly striking: an observer receiving the sequence of the realized Q_n factors would have great difficulty tracing their formative law.

IV. FINAL REMARKS

We have presented in these pages a *catalogue*, that of the principal instruments forged by physicists and chemists for the study of cooperative phenomena. As in any catalogue destined for a wide public, the items are not furnished with descriptive technical labels, but each has a brief text suggesting possible use. Technical labels exist—and the references we have given permit their accessibility. But there are two things to fear: one brings the reader to a halt, the other carries him too far.

1) The complexity of "technical labels": scientific literature is based on a language requiring about eight years to learn and for which at present there is no accelerated course. How can this barrier be overcome?

2) The fetishistic cult of the scientific tool: we have seen the appearance of such a cult around a method or a particular formalism in many developing sciences. The physical sciences themselves are subject to this failing.[20] Thus, when a supplementary tool is proposed to the researchers there is a real

[20] P. G. DeGennes, "Leçon inaugurale," Collège de France, 1971.

danger of excessive and dogmatic use. How may cooperative effects of this sort be avoided?

In my opinion, the solution to these two problems does not lie in the drawing-up of "simplified technical labels." No explanatory work by a single author can keep its readers from taking one or the other direction. Real progress will only be made by the formation of *mixed working groups*, in which different scientific disciplines come together to combine their data and participate in a common creation. An action of this kind is currently making its debut apropos of the history of science.[21]. Let us hope that it succeeds and that other groups having different objectives will spontaneously appear—by means of one of those instabilities which we would like to understand, in time.

(The author wishes to thank many colleagues for their criticism and advice, especially J. de Ajuriaguerra, A. Pacault, and K. Pomian).

[21] Under the motivation of Klapisch and Pomian.