STRUCTURAL CHANGES IN OPEN SYSTEMS: THE CASE OF COGNITION

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Invited paper presented at the International Conference "Evolution and Cognition: The heritage of Jean Piaget's genetic epistemology in science and in philosophy, between the 20th. and the 21st. century".

Bergamo, Italy
5 - 8 October 1990.

INTRODUCTION

A scientific theory constitutes an instrument to organize and interpret facts, phenomena or situations within a given domain that were without a common explanatory framework. The history of all long standing scientific theories shows that none arose in a perfectly finished form in the mind of its creator. It is a a dynamic history that has consisted of restricting domains of applicability in some directions, extending them in others, giving further precision to fundamental concepts, refining some formulations and, in certain cases, subsuming the theory in conceptualizations of a wider range that contain it as a particular case.

Theories are not a set of propositions, they are organized totalities. For this reason they are not just rejected when some of the propositions deriving from them are shown to be invalid. A theory is abandoned only when another theory is found capable of explaining what the former explained and of extending the domain of validity into areas where the former had failed.1

Taken as a whole, the work of Jean Piaget comprehends an impressive accumulation of psychogenetic and historical researches, aimed at providing the basic elements for

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1 This explains how the Aristotelian theory of movement remained established for 2,000 years, in spite of numerous refutations throughout the centuries.

constructing a general theory of the development of knowledge.

The above considerations - that are common place in the philosophy of science today - lead to an analysis of Piaget's work from a global perspective which, in my view, allows us to put aside as irrelevant much of the criticism of Piagetian epistemology.

Such considerations lead centering the analysis of the validity and the perdurability of Piagetian theory on the processes which determine the development of knowledge and on the mechanisms governing them. Genetic epistemology is an attempt to articulate the elements provided by an enormous diversity of relevant researches carried out by the Geneva School. The outcome is an explanatory system with the characteristics of a coherent theory, whose enunciates (paraphrasing a dictum of Quine) confront the tribunal of experience, not individually, but as a collective body.

In this respect, the nucleus of Piagetian epistemology is the theory of equilibration. It is not my intention on this occasion to analyze its content. The objectives of this paper are others.

A first objective is to establish the different meanings and range of the concepts of equilibrium and equilibration in different moments in Piaget's work. This requires a brief reconstruction of their history, but without the intention of carrying out an exhaustive study. This reconstruction shows that the interpretations found in numerous presentations of the theory of equilibration are inadequate.

In general profound differences in content and scope throughout the history of the theory are ignored as if the question was one of formulations of the same "problematique", to which additions were made. The analysis is usually limited to differences in the explanations of the mechanisms of equilibration found in the two volumes in which Piaget presents his ideas on equilibrium and equilibration in a unified manner. The volumes correspond to two different moments in his scientific work, with twenty years between them (Piaget, 1957, 1975). The first is usually referred to simply as containing "the first version" of the theory, that was later abandoned when the "new model" of the second of these works was formulated. Even an author like H.G. Furth (1980), a careful and profound commentator of Piaget's work, refers to Piaget (1975) as Piaget's "new model" of equilibration (Piaget's "New Equilibration Model", Chapter 15).

In this paper we will present a reconstruction of the history of the theory which shows that such interpretations are not acceptable. Piaget (1957) and Piaget (1975) are two different theories, the second completely replacing the first in that it asks <u>different questions</u> about the evolution of the cognitive system. Thus, we are not dealing with two different models attempting to explain the same 'problematique', it is the latter that has varied. The second of the two involves the first but requires a different type of answer.

The second objective of this paper is to show that Piaget's theory of equilibration is a particular case of the theory of the self-organization of open systems. I have dealt with this theme on other occasions (cf. Garcia ( ) & García ( )). Here I propose showing that the 'problematique' of the general theory of stability, destabilization and reorganization of open systems has undergone an evolution surprisingly parallel to Piagetian theory. From this point of view, many of Piaget's critics arrive at a paradoxical situation, that we can summarize in the following manner. One of the most persistent criticisms refers to the notion of stage introduced by Piaget in his psychogenetic research. For example, Margaret Boden (1979) declared that "the stage-concept has become increasingly dubious" (Boden, 1979, p. 152). The doubts seem to have increased with time, even among ex-collaborators (e.g. L. Apostel) and ex-disciples of Piaget, the so-called neo-Piagetians. Today, on the contrary, the idea, <u>originating with</u> Piaget, of an evolution through successive reorganizations, under the influence of external "perturbations" which are not compensated for, has been <u>demonstrated</u> in physical, chemical, biological and social open systems. The situation has been reversed. Now the detractors of Piaget, who also tended to accuse him of not having put enough emphasis on the characterization of the cognitive system as an open system, open to the action of society, have to take note of the fact that "gradualism" in the development of knowledge would be an exceptional case in the evolution of an open system!

The above comments are purely anecdotal. We will try to show that what is important is that during recent decades there has been an extraordinary advance in the discovery of evolutionary mechanisms that are common to very diverse domains of phenomena. This statement in no way weakens the specificity of each domain regarding a particular type of phenomena, nor does it constitute a reductionist proposal of the "unity of science" type associated with logical empiricism.

The progress that has been made has profound implications of an epistemological nature. In particular it requires the revision of classical concepts that are now questioned from various angles. Such is the case of concepts like "determinism", "predictability" and "chance" whose definition and mutual relationship has been totally modified.

From the perspective that we shall adopt here, Piagetian theory anticipated many ideas and opened up paths in unexplored territory. Reciprocally, the current developments allow more precision and the clarification of concepts which, as in the work of all pioneers, were fairly ambiguous and their role in the theory not clearly formulated.

Doubtless there will still be critics who will insist that these theorizations are too general and don't explain the specific behavior of "a real subject acting in the here and now". Such critics have to be reminded that the history of science shows us that the passage from "the here and now of Peter and John" to the general principles of a theory is the work of a genius, while applying these principles to Peter and John is the task that Kuhn has called "normal science".

I. Equilibration and equilibrium of logical structures.

The notions of "equilibrium" and of "equilibration", in reference to the cognitive system, occur early on in Piaget's work. Both notions acquired a growing importance in genetic epistemology, to the point that equilibration became the central concept in the explanation of the development of knowledge. But during the process, not only did the meaning of the concept become enriched, but also the problems to which it referred varied in a very profound manner. This is the source of our refusal to accept the idea of "the two models of the theory of equilibration". As I indicated in the Introduction, they were not two models of the same theory, but two different theories. As the "problematique" varied, so did the type of question that Piaget asked at each moment. For reasons that will be immediately obvious, I prefer to designate these theories as the "restricted theory" and the "general theory" of equilibration.

The initial emphasis on the concept of equilibrium responds to an unavoidable issue within the constructivist conception of knowledge. The starting point can be condensed in three assertions that constitute the elements of the theory:

- all process of assimilation consists of the incorporation into the cognitive system of external elements (objects, events) which constitute the content to which the subject imposes forms of organization.

- the forms of organization correspond to the logical structures that the subject has constructed in preceding stages, and which begin with the first coordinations of action schemes.

- this construction culminates in the logic employed by every adult and which remains stable from adolescence onwards, and which constitutes the final equilibrium arrived at by the constructive process.

The explanation of the stability of natural logic is the culmination of a long road taken by Piaget in his research on the genesis and development of logical structures. The absolute priority that Piaget gave to these researches, throughout the initial period in the development of his theory, is the result of a requirement of his epistemological conception that, in this context, can be synthesized in the following basic statement, which we quote here in one of his later formulations, but which has numerous and well known antecedents:

- "it is impossible to discover any content without a structuring that involves at least a partial isomorphism with logic: thus, the logical-mathematical structures, as well as the pre-logical and pre-mathematical structures that sketch the former, constitute instruments for the acquisition of knowledge, and not just a-posteriori coordinations" (Piaget, 1959; Page 119 of the re-edition, Piaget, 1964).

This central thesis of Piagetian epistemology gives a basis to and justifies his emphasis on the genesis, development and completion of natural logic, and the search for an explanation of "final equilibrium" as well. From this perspective the frequent criticisms as to the "hyperconstructivist tendency" in Piaget, or the "idealist bias" that is attributed to the work of the Geneva school, lose meaning.

The concern with the genesis and the "final" equilibrium of logical structures does not in any way exclude the consideration of content. In reference to the learning of content, Piaget (1959) writes:

"From the point of view of equilibrium, this learning of content is characterized by a gradual, but always unfinished, equilibration between assimilation and accommodation, while only the logical-mathematical structures realize this equilibrium in a permanent form" (page 50).

This thesis complements the previous one. The incorporation of "content" to a more general theory of equilibration was to occupy another decade of research by the Geneva school, not because they were unaware of the theme or minimized it, but because there was still a lot to analyze in the previous context. But we should not fail to emphasize the fact shown above in what we called the central thesis of Piagetian epistemology according to which the variety of psychogenetic researches carried out on all sorts of content reveal the same type of evolution of logical structures that permit the assimilation of these contents. The possibility of formulating a theory of the development and equilibration of logical structures without reference to any content is found here. This theory can be accepted or refuted on the basis of another alternative epistemological theory. But to qualify it as "hyperconstructivist", as "an obsession with form" or as "idealist" simply means that the bases have not been understood.

In order that the three preceding assertions constitute a theory that contributes to clarifying which conditions are necessary for the development of knowledge (not yet a theory explaining the cognitive system as such), it is necessary to answer two fundamental questions:

- what does the genetic development of logical structures throughout the various stages of childhood and adolescence consist of?

- what is the mechanism that maintains the stability achieved by the logic of the normal adult in the final stage?

The reply to the first question is found in the psychogenetic analysis of the famous "stages", an obligatory reference for all exponents of genetic psychology and, at the same time, without doubt the most distorted and trivialized notion in Piagetian theory (cf. Piaget & García, 1987, Chapter).

The second question marks the precise limits of the restricted theory of equilibration. It is not equilibration (or the successive equilibrations of the cognitive system) that is at issue. What is involved here is only the stable equilibrium (albeit dynamic) achieved by the natural logic used by all adults. The reply to this second question is found in Piaget & Inhelder (1955). The following paragraph condenses the explanation:

-"The system is in equilibrium when the operations the subject is capable of constitute a structure such that these operations are susceptible to developing in both senses (by strict inversion or negation, or by reciprocity). In other words, the set of possible operations constitutes a system of virtual transformations that compensate for each other - in so far as they obey the laws of reversibility. This is what makes the system capable of remaining in equilibrium" (pp. 235/236).

This concept of *operatory equilibrium* is previous to the badly misnamed "first version" (or "first model") of equilibration that is found in *Logique et Equilibre* (Piaget, 1957), and was not later modified. The conception of stages that precede formal operations as periods in which a partial equilibration is reached, is also previous to this work. Thus, for example, Inhelder and Piaget (op. cit.) indicate that "the equilibrium achieved by concrete thinking still presents a relatively restricted field and consequently remains unstable at the borders of this field" (p. 218).

Logique et Equilibre was to maintain and to further elaborate this interpretation of the development of logical structures and, in particular, the conception that they finally arrive at "an interaction of compensations that *guarantees a permanent form of equilibrium* (p. 111, author's emphasis). I propose calling this particular theory the "restricted theory of equilibration". The only new element added by this book is an attempt at a probabilistic "explanation" of the successive *partial re-equilibrations* . This interpretation was to be eliminated later since it is not valid when the theory - that it was restricted up to here to *operatory equilibrium* - is extended to give way to the *general theory* of the equilibration of the *cognitive system*.

II. The equilibrium of a biological organism and the thermodynamics of irreversible processes in open systems

During the same period in which Piaget was concerned with explaining the operational equilibrium of natural logic in adults, some biologists including Piaget himself who was also a biologist, sought explanations for that form of dynamic equilibrium arrived at by a biological organism in its adult state.

The article on "The mental development of the child" (Piaget, 1940) deals simultaneously with both problems starting in the first paragraph:

"The psychic development that begins at birth and ends in adulthood is comparable with organic growth: like the latter, it consists essentially of a march towards equilibrium. In the same way, in effect, that the body is in evolution until a relatively stable level is reached, which is characterized by the termination of growth and the maturation of the organs, similarly mental growth can be conceived of as evolving in the direction of a form of final equilibrium represented by the mind of the adult".

We have already looked at the form in which Piaget formulated and explained this "final equilibrium", in reference to "mental development".

In the case of biological equilibrium, it was Bertalanffy who formulated the problem, perhaps for the first time, in a precise manner. In the same year, 1940, he published his article "The organism as a physical system" (reproduced in Bertalanffy, 1968) in which he puts forward the idea of considering the organism as an "open system". Within the framework of what he was to call a General Theory of Systems.

"The organism is not a static system closed to the outside and always containing the identical components; it is an open system in a (quasi)-steady state in spite of a continuous change of component material and energies, and in which material continuously enters from, and leaves into, the outside environment. The character of the organism as a system in steady state is one of its primary criteria. In a general way, the fundamental phenomena of life can be considered as a consequence of this fact".

The problem formulated by Bertalanffy is how a system that is far from thermodynamic equilibrium may remain in a steady state and in constant exchange of material and energy with the external environment. The thermodynamics of irreversible processes, whose systematic analysis is largely due to the impulse it was given by Prigogine during the mid-1940s, gave a precise answer to this question (Prigogine, 1947, 1955).

Classical thermodynamcis - as is well known - is fundamentally restricted to the study of reversible processes and states of equilibrium. Its application is limited to the domain of <u>closed systems</u> and, more particularly, of <u>isolated systems</u>.[2]

The introduction of the concept of <u>entropy</u> by Clausins permitted the definition, in this formulation of thermodynamics, of a mathematical function that remained constant in the reversible processes and which increased monotomically in the irreversible processes (2nd. principle of thermodynamics). Applied to the "entire universe", this principle led W Thompson (Lord Kelvin) to predict "thermodynamic death": in an isolated system equilibrium is reached when energy is uniformly distributed, implying the disaggregation of all the structures. It is thus understandable that biologists have sustained the inapplicability of thermodynamics to biology, since - as Bertalanffy wrote - a living thing remains as such and conserves a stable structure because of continuous exchange with the external environment, that is, because it is an <u>open system</u>.

In the study of irreversible processes, Prigogine established an important distinction between the <u>state of thermodynamic equilibrium</u> and the <u>steady state</u> of a system far from a situation of equilibrium.

In the publications mentioned, Prigogine analyzes in particular steady states "that may be characterized by an extremum principle which states that entropy production has

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2 A "closed" system permits the exchange of energy but not of material with the external environment. The "isolated" system does not exchange material or energy.

its minimum value compatible with some auxiliary conditions to be specified in each case" (p. 75). The result that interests us here is the demonstration that "when a system is in a state of minimum entropy production, hen it cannot leave this state by a spontaneous irreversible change. If, as a result of some fluctuation, it deviated slightly from this state, internal changes will take place and bring back the system to its initial state, which may be referred to as a stable state, the transformations which occur in such a state may be called stable transformations" (p. 83).

The similarity between the preceding explanation of the steady state outside thermodynamic equilibrium and the operatory equilibrium described by Piaget is striking. In both cases we have states of dynamic equilibrium characterized by what Prigogine calls "stable transformations" and Piaget refers to as "reversible transformations". In both cases these are no more than transformations capable of compensating for perturbations (I will return to this theme further on).

The book concludes with a significant paragraph: "It is in regions of space where such stationary states occur that we may have a specially high organization measured by a low value of the entropy. Therefore such states may be expected to have a special importance from the point of view of the evolution of life" (op. cit., p. 107).

Once again here we can see the identity of the "problematique" posed by posed and by Prigogine at the beginning of the 1960s: how does a system (cognitive, in one case, chemical and biological, in the other) achieve a stable organization and maintain it. Towards the end of the decade, both the Geneva school and the Brussels school had widened the range of the "problematique" which was to develop once again with an intriguing parallelism.

III. The equilibration of the cognitive system

In section I, I referred to the theory of equilibration of logical structures, showing its independence from the explanation given in Logique et Equilibre as to the mechanism that determines the successive re-equilibrations until operatory equilibrium is reached (sequential probabilistic processes). The mechanism is plausible because the analysis is restricted to a succession of logical structures. However, it lacks explanatory capacity when not only operatory equilibrium is to dealt with, but a general theory of the cognitive system proposed; then the weakness of the explanatory scheme becomes evident. Despite the risk of being repetitive, it is necessary to insist that neither the interpretation of operatory equilibrium, nor the interpretation of the succession of stages depends on this probabilistic explanation. In the wider theory, this explanation can be easily abandoned, but not the interpretations.

Causality and the general theory of equilibration

Towards the end of the 1960s, the researches of the International Centre of Genetic Epistemology were to concentrate on the study of causality and a profound rethinking of the problems involved in the development of the cognitive system. This was to be the source of the general theory of equilibration.

Piaget anticipated the need for this reformulation from he very moment that he announced "the renovation of the field of studies". At the end of his autobiography (Piaget, 1966) he writes,

"These projects for the future are multiple and varied. I will only mention one which for me has already produced the effect of a renovation in the area of cognitive operations themselves. While studying the development of logical-mathematical operations, we have above all other issues insisted on the spontaneous activities of the subject since, in effect, we are dealing with the results of his actions and his thought. But after old and now surpassed work, we have not dealt much with causality, beginning with the causal effects of action itself and not with the internal logic of action. But causality is an operation attributed to objects and not simply applied to them. To systematically take up once more the study of causality is thus to begin the analysis of cognitive development again, but now from the point of view of the object and not that of the subject: here is an immense domain which may well hold many surprises".

Part of the researches on causality were published in various volumes, and many, whose analyses he did not conclude, were not edited. This is the source of Les Explications Causales (Piaget-Garcia, 1975). In the "Avant Propos", Piaget declares,

"the development of causality presents much more difficult problems than the study of the operations of the subject (...) To explain a physical phenomenon certainly supposes the employment of such operations (...) But the responses of the object are added, and this is essential".

The new "problematique" was to be developed on the basis of the above, because the assimilation of content does not consist of a process of successive partial equilibrations that conclude in a state of "final" stable equilibrium. The cognitive system as a whole (that is, form and content), undergoes successive de-equilibrations,

"The problem of the passage from initially undifferentiated cognitive structures and, for this reason, a source of internal oppositions, to structures which are at the same time differentiated and coordinated in a coherent manner, in reality dominates all mental development in its fundamental processes of progressive equilibration, periodic disequilibria and constant re-equilibrations". (p.120).

When the problem is formulated in this manner, disequilibration becomes the central problem to solve. The probabilistic interpretation of the restricted theory loses its explanatory power. The theory has to be formulated anew, from the beginning.

The solution to the problem of disequilibration is already announced in this book. The following quotations are sufficient evidence of this.

"In all domains ... the notions of structures, undifferentiated from the outset, enclose implicit or explicit contradictions to different degrees".

"the driving force of the differentiations and their solidarity with the coordinations should be sought in the dialectical processes that provoke the contradictions".

"To raise contradictions is, in effect, to construct a new operational structure". (p. 122).

The research which led to a basis for this latter assertion are found in the two volumes on contradiction (Piaget, 1974). We will only take two quotations which clearly define the objectives and the conclusion.

"The objective of this work is to look for the relationship between contradiction and the disequilibria of action or thought". (Introduction).

" ... the examination of the relationships between contradiction and disequilibria is complementary to the relationships between the reversibility of thought and equilibration". (p. I-10).

These two works, Les Explications Causales and Recherches sur la contradiction, contain the bases of the general theory of equilibration which was to be presented in Piaget (1975), in the book whose title L'Equilibration des Structures Cognitives indicates the change of "problematique" with respect to the 1957 text.

I will only take tow quotations which confirm the displacement of the problem from the explanation of operatory equilibrium to the explanation of the successive disequilibrations generated by the perturbations that the system undergoes in the form of contradictions,

"The disequilibria (or contradictions) result in the conflicts that all historical development implies, due to the diversity of systems or sub-systems, observables and coordinations, and to the fact that none of these carefully accomplished from the start (causal systems never are) and that they develop at different speeds (p. 18).

" ... the subject tries to avoid incoherence and consequently tends towards certain forms of equilibrium, but without ever achieving them, except sometimes in provisional stages; even regarding logical-mathematical structures whose closure insures local stability, this completion constantly opens on to new problems as a result of the operations that could still be constructed on the preceding ones. The most elaborated science thus remains in continuous development and in all domains disequilibrium plays a functional role of the first importance since it requires re-equilibrations". (Conclusion, p. 170).

IV. <u>The disequilibration of dissipative structures</u>

In the same year that Piaget published the general theory of equilibration of cognitive structures, an article by Prigogine and Lefever called "Stability and Self-Organization in Open Systems" appeared in the publication <u>Advances in Chemical Physics</u>, vol. 29 (1975). Here, the authors comment on a paper by Martinez (1972) in which it is demonstrated "how, in the course of development, a system of cells can evolve by a succession of instabilities through a set of distinct states". This paper points out that "in order to regulate such a passage, not only must the system be unstable, <u>but also the instabilities must in some way regulate the boundary conditions of the system</u>".

The comments made by Prigogine and Lefever are worth quoting here,

"An important feature of self-organization and development, viewed as <u>a succession of instabilities, which must be stressed, is the fundamentally irreversible character of the whole process</u>: Each time the system reaches a point of instability, it spontaneously and irreversibly evolves toward a new structural and functional organization; furthermore, these jumps can occur only at given time instants after the beginning of the whole process; in other words, the system has a natural time scale of irreversible aging associated with its own internal properties. In some senses, one could be tempted to think that we have here a first approximation of what biologists describe, in the evolution towards highly organized states, as the successive integration of levels of increasing structural and functional complexity."

We might add that the temptation to associate that "important characteristic of self-organization" with Piagetian theory is even greater. In effect, we have here the totality of the elements that characterize the evolution of the cognitive system according to the Piagetian theory of equilibration:

- Evolution takes place as a succession of instabilities that pass "through a set of distinct states" (that Piaget calls "stages"?)

- The process is irreversible; the instabilities lead to a reorganization of the system, generating a new structure that remains stationary until it is de-stabilized by new perturbations.

- The structural changes take place according to a temporal scale "associated with the internal properties of the system".

- The instability (period of transition towards a new structure) also regulates the exchanges of the system with the external environment (boundary conditions).

V <u>Fluctuations, instability and boundary conditions.</u>

For our present purposes we will only refer to he following development of the theory. In a series of papers written by Prigogine, Nicolis and collaborators, the group's attention appears to have centered on the role of fluctuations in the formation of dissipative structures and, in particular, on the mechanisms that trigger the instabilities.

Detailed studies of chemical systems led to the idea that the behavior of fluctuations in non-linear systems far from equilibrium depends on their space dimensions. The important result is that only fluctuations beyond a critical size may trigger the appearance of an instability. The conclusion is that "the onset of non-equilibrium instabilities in macroscopic systems is due to the deviation of the fluctuations fron the Poisson distribution " and to "fluctuations of a certain size and range appearing spontaneously in the system" (Nicolis & Prigogine, 1977)

In the introduction to their book the authors make the following comments: "Beyond the instability, the statistical fluctuations increase in time and finally drive averages to their new macroscopic state. We see here very clearly the menaing of the concept of order through fluctuations (...) We may consider such processes as expressing a breakdown of the 'law of large numbers'. When this law is satisfied the average provides an adequate description of the system. Here, on the contrary, fluctuations drive the averages".

There is no doubt that the mechanism described above is well established for the cae of chemical processes. However, the relation cause-effect between the growth of fluctuation and instability does not seem to be universal.

We have referred elsewhere (cf. Garcia, 1990) to an experiment that demonstrates an inverse mechanism. This is the ase of a thermo-hydrodynamic system consisting of a cylindrical tank, with a central axis and arotation mechanism. The annulus between the outside wall of the tank and the axis is filled with liquid. A thermoelectric devie allows a temperature difference, which can be regulated, to be established between the axis, which is kept at a constant temperature, and the outside wall.

The experiment starts from an initial state in which the fluid rotates togethr with the tank and the temperature gradient is absent. Then, the temperature of the outside wall is increase gradually in a continuous and linear fashion. The pattern of the current in the fluid in its inital state is circular (when observed from above), and then becomes chaotic when the internal temperature gradient exceeds a certain value. The gradient continues to increase without interuption in a continuous and linear manner. After a certain moment, the movement of the fluid becomes organized in a wave pattern (with two or three waves). The process continues as a succesison of "ruptures" of th structure of the movement of the fluid, passing through a chaotic stage to once again re-organize in more an more complex patterns (with increasing numbers of waves) until reaching a final state of permanent turbulence.

In this experiment, the boundary conditions play an important role, since it is the increase in the outside temperature that introduces the "perturbations" in the system. Each pattern is maintained, with fluctuations, within certain ranges of thermal gradient. There is a critical value of outside temperature increase for each pattern which destabilizes the movement. This means that a parcel of the fluid, separated from its trajectory by a fluctuation, however, small, is submitted to forces that separate it further from its path. Here, instability makes the fluctuation increase and not vice-versa. Chaos is generated by the instability. The system is driven by a forcing function imposed by the varying boundary conditions.

Why does the system re-organize?

Obviously the instability provokes random motion. The parcels of the fluid follow disorderly and arbitary trajectories. What we have is a situation of chaos: the instability opens up the possibility of all sorts of displacements. However, some of these displacements, at random, will coincide with trajectories that are stable with respect to the range of values that the thermal gradient acquires at that moment. As a result, those parcels of the fluid remain on that trajectory. The others continue their random motion until there are further coincidences with stable trajectories. The fluid is "ordered" once more, and a current pattern is set in that will maintain stability until the gradient reaches new critical values. "Stable" referes to steady state motions with fluctuations that are "compensated for" by the thermo-hydrodynamic forces in action.

In this experiment it is the conditions of stability or instability that determine whether the fluctations will remain bounded or will grow. The role of the boundary conditions is clear enough. The heat flows across the outer boudnary of the system modify the internal gradients and generate the situations of instability.

This interpretation of the mechanisms of destabilization and reorganization of the thermo-hydrodynamic system that we have looked at here has allowed us to explain the evolution of much more complex open systems (cf. García, 19), where the flows across the boundaries are the key factors regulating evolution.

The evolution of the cognitive system in the case of an individual subject appears to obey similar mechanisms. Here, the boundary conditions are determined by the interactions of the subject with the "outside world". We have already indicated the role of contradiction in he Piagetian theory of equilibration, as a factor destabilizing the system. These contradictions arise when the explanatory system of the subject cannot solve problems that occur in new situations he mist confront. :To raise contradictions is to construct a new operatory structure (...) When the contradictions refer to the interpretation of badly recorded or poorly explained facts (...) then a new causal structure has to be elaborated". ( ).

If we conceive of the cognitive system of an individual subject as a system immersed in a social an physical environment that determines its boundary conditions, the role of society in psychogenesis takes on a new perspective that, in my view, may clarify some aspects of the Piagetian theory that has been the theme of unending discussions. But this is an issue requiring extensive development and we shall have to leave it for another occasion.