Giuseppe CAGLIOTI*

TRANSFORMATIONS OF PHYSICAL SYSTEMS AND TRANSITIONS OF HUMAN SOCIETY

Abstract: We propose a comparison between the transformations of physical systems away from thermodynamic equilibrium and the transitions of human society. Three parameters seem sufficient to propose a schematic description of the process of evolution of both transformations: the nature of the structural components, the control parameters and the order parameter. In the context of the analogy proposed here, the increase of the consumption of energy and the unscrupulous use of the territory seem to push here ad there segments of the human society towards the deterministic chaos, ie towards a dynamic organization characterized by complex correlations so intricate that it becomes impossible to find the thread.

Key words: *physical systems, human society, control parameters, order parameter, ransformations, energy, information, deterministic chaos*

INTRODUCTION

An analogy is presented between the transformations of physical systems and the transitions of human society. The fractal geometry of nature and the thermodynamics of physical systems removed away from equilibrium offer a guideline for a study of the evolution of human society and, possibly, for the identification of a trend. The proposed analogy might appear risky. Only in certain circumstances the components of the natural creatures and of the human society show a behavior similar to the behavior of the atoms of physical systems. However, it seems legitimate to propose that in all circumstances two parameters are crucial to describe the evolution of the said transformations: the control parameter and the order parameter. In the context of the proposed analogy, the increase of consumption of energy and materials and the rate of dissemination of information among people seem to push the society, at lest locally, towards the deterministic chaos, ie towards dynamic correlations so complex and tangled that it is impossible to find the thread.

* Professor Emeritus – Structure of matter, Politecnico di Milano, Energy Department, Italy

1. TRANSFORMATIONS OF PHYSICAL SYSTEMS

The book *Fractal Geometry of Nature*, published 30 years ago by Benoît B. Mandelbrot has marked a turning point, a revolution in our vision of the world:

Why is geometry often described as 'cold' and 'dry'? One reason lies in its inability to describe the shape of a cloud, a mountain, a coastline, or a tree. Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line.

Mandelbrot's fractals exhibit striking similarities both with biologic creatures and physical systems removed far from thermodynamic equilibrium by external resources – matter, energy and information.

But what is a fractal? A fractal is a *self-similar* structure, each part of which is a copy of a part of the structure, and possibly of the entire structure. A familiar example of a natural fractal sculpture is the Roman cauliflower, *Brassica Botrytis*: each tuft of the cauliflower is a faithful copy of the entire cauliflower. Under a magnifying glass a tuft of the cauliflower's tuft appears indistinguishable from the whole cauliflower. Another example of a fractal: boiling water. In it, the vapor phase and the liquid phase are contending for the water: so that, at equilibrium, the dispute is resolved in a critical configuration, in which a lake of steam contains islands of water droplets within each of which there is a small lake of steam that contains islands of water droplets inside of each of which … The ***self-similarity*** of fractals is a symmetry, ie a form of invariance characterized by no change as the outcome of an enlargement or a reduction of the scale. This scale invariance must be the result of a process which, in turn, presents a form of invariance. this form of invariance is characteristic of the ***self-organization***. Simple computer programs allow you to build fractals by mapping the plane: from a point on the plane you go to another point of the plane following a rule, from the point thus obtained, following the same rule we pass to the next point …, iterating systematically the same rule. The rule is expressed by a non-linear mathematical formula, a simple formula which nevertheless is able to produce a myriad of apparently complex images. Heinz-Otto Peitgen and Peter Richter, in their world bestseller *The Beauty of Fractals*, illustrate admirably the galaxy of images generated by the recursive formula $z_{n+1} = z_n^2 + c$: a formula which, once it has been arbitrarily fixed one of the infinite possible values of the complex number c, regulates the succession of the n, $n + 1$, $n + 2$, … stages of the process of mapping the complex plane z.

So it becomes possible to simulate the aggregation of ferns and sponges, the discharge of lightning, the formation of a cloud and the texture of the dendritic arabesque that the ice forms on the windshield of our car parked in the open in a damp winter night. each molecule of water vapor that is going to be incorporated in the pre-formed aggregate responds to the same laws of force that had regulated and will regulate the aggregation of the previous and the next molecule The biological creatures have the typical self-similarity of fractals, in every fragment of their structure is concentrated the information inherent in the whole structure: think of the DNA test for the identification of individuals.

In the introduction of his book *Fractals Everywhere* (1988) Michael F. Barnsley writes:

Fractal geometry will make you see everything differently. There is a danger in reading further. You risk the loss of your childhood vision of clouds, forests, flowers, galaxies, leaves, feathers, rocks, mountains, torrents of water, carpet, bricks, and much else besides. Never again will your interpretation of these things be quite the same.

Do not be so surprised if fractals, always present in nature and embedded in the culture, come overbearingly in the world of physics, botany, biology, astronomy and medicine, and even, as proposed by Mandelbrot, in 'the (mis)behavior of the financial markets'. And so, today, we recognize self-similarity in the Hindu dogma, according to which if it is true (and it may appear trivial) that the universe consists of all its parts, it is also true that every part of the universe contains the whole universe. In parallel, we recognize self-similarity in Hindu temples, architectural projections of this dogmatic conception of a self-similar cosmos

A classical example of dynamic transformation of a physical system occurring almost everyday in our kitchen is the Rayleigh-Benard instability of a liquid (or an emulsion) heated from below. While the water or a soup are being heated, their average temperature increases as a consequence of the heat diffusion. Initially this diffusion is not accompanied by macroscopic displacement of matter: the liquid keeps still, while a temperature gradient builds up in the liquid itself: the lower portion of the liquid, close to the heat source, becomes gradually hotter than the upper one. This gradient points upward, in the opposite direction of the acceleration of gravity. In this inverse temperature gradient the liquid layer near the bottom of the container experiences an Archimede's buoyancy force. This force pulls the lower, hotter layer toward the upper, colder region of the container. But it is contrasted by the viscosity and the action of the thermal diffusivity, whose trend is to homogenize the temperature of the liquid. However, as the inverse temperature gradient attains a critical value, the buoyancy force prevails and the whole volume of the liquid puts itself into convective motion; at this critical point the ingoing thermal power exceeds the capacity of the liquid to absorb the heat merely through an increase of the average temperature of the still liquid, and the excess power comes out toward another, non-dissipative channel: it acts effectively so as to generate dynamically an ordered field of temperature and velocity inside the liquid. In perhaps simpler words, at and beyond the critical state a part of the ingoing energy is transformed into kinetic energy of coherent, convective motions of the liquid along dynamically selforganized patterns while the complementary part is dissipated. The diffusion-convection dynamic instability now described is characterized by

- the control parameter, specifically the ratio between the buoyancy force and the product of the counteracting viscous and thermal diffusivity forces;
- the order parameter, specifically the amplitude of the velocity and temperature field.

The Giant's Causeway in Ireland offers a spectacular image of the crystallized outcome of diffusive-convective instability of the lava produced in a gigantic volcanic explosion.

2. TRANSITIONS OF HUMAN SOCIETY

So far we have described the mechanisms regulating the creation of natural structures. And we have highlighted the role played by the self-organization in this creating process. Self-organization. starts from a collection of subsystems unstructured, undifferentiated, and, at the origin, statistically symmetric; the result of the process is a product which has a residual symmetry, the self-similarity, and exhibits new properties.

Not only in the transformations of physical systems but also in the transitions of human society the emergence of a residual symmetry is always accompanied by the onset of correlations, order, collective behaviour and new properties.

If the constituent modules are a set of atoms or molecules, their interactions can be described in a simple way. Typically it comes to attractive forces that generate well-defined chemical bonds – covalent, ionic, metallic, van der Waals, hydrogen bonds. At the atomic level structural modules are often indistinguishable and this fact simplifies the study of their behavior during the structural transformations.

If the constituent modules are individuals their interactions are much more complex. However something similar to the indistinguishability can be realized in special circumstances, when the survival instinct, the tendency of imitation (most likely promoted by the mirror neurons) and an important objective tightly shared unite individuals firmly, triggering their solidarity. Think for instance to a flood of refugees escaping from an oppressive regime, to the slogans in the political or trade union demonstrations or to the synchronized, rhythmic applause of an audience that wants to get an encore at the end of an exciting concert.

In all other cases the modalities and the pattern of the transition are not predictable.

Resources such as energy and materials exert only partial control on social transitions. Also the information, disseminated by the television and the web, has a controlling influence on these transitions: the information – which could be defined as removal of uncertainty and entropy, and therefore as the quality of energy – exalts the predisposition of individuals to imitate each other, but can not unify their behavior rigidly.

Anyhow, some reflections could be proposed concerning the role played by the energy as a control parameter of the transitions occurring in the human society

In an agricultural society whose rhythms were controlled by the daylight and by the recursion of the four seasons, in a society where the Sun was practically the only source of energy, interactions between individuals were extremely weak

However, since the times when the hay for the horses was the main source of mechanical energy, the average rate of the *procapite* energy consumption is increasing by 0.3% per year. As more and more energy is fed into society, the society is removed farer and farer from equilibrium. At the same time, more and more order and correlations are produced irreversibly (at the price of a dissipation that cannot be set aside).

The availability of energy has allowed the world population (and the *global* consumption of energy) to increase rapidly. In the countries where the procapite yearly energy consumption reaches the threshold of order of 2.7 tons of equivalent oil, a transition occurs from agricultural to industrial society. In those countries people are more and more conditioned by technology: the dramatic impact of an accidental blackout on the life of a megalopolis reminds us that we are embedded in a world populated by artificial structures: the artificial predominates nowadays on the natural. Furthermore the unscrupulous use of the territory implies a dramatic rate of extinction of living species. In order to insure his survival, man consumes daily about ten thousand kilocalories. In order to enjoy superfluous goods that, in developed countries, are considered necessary, man consumes an amount of energy about nine times larger than that indispensable to life.

Using the terminology of nonlinear irreversible thermodynamics, the energy flow injected into the society and the rate of transfer of information act as control parameters of the society. Here and there, segments of the human society are removed farer and farer away from "thermodynamic" equilibrium. Their distance from equilibrium acts as a source of order. The organization that emerges from all this evokes the capriciousness of the climate changes we experience nowadays: it becomes more and more complex, contradictory and chaotic (chaos is conceived here as a form of dynamic order tangled to the point that we get muddled).

To say it with Edoardo Boncinelli, *Everyone is in a hurry to find the time to not go in a hurry.*

And perhaps now it is the right time to stop at this point.