A darwinian metaphor. Objects, artificial systems and technological mutations in an evolutionary perspective

Beyond the fundamental and irreductible difference between the finalist nature of biologic evolution and the intentional nature of human activity, between the random processes that regulate natural forces and the direct control exercised on the technological field, the most generalized ideas on the isomorphology between biology and technology have constituted an object of research of heterogenous disciplinary fields that have developed some of their specific aspects. Of these studies, some are only relatively well-known, as is the case of the theoretic contributions to the concept of progress in living systems and technological systems.[1] In this direction, a first bio-technological approach began in the 1930's, with the studies of the German zoologist Franz,[2] the use of comparative study to arrive at a better understanding of biological evolution; the term «biotechnical progress» was introduced in this case to define the structural and functional improvements of organisms which could be measured through their efficiency.

The meaning of *progress* in living systems and in technology immediately became the object of specific theoretic speculation, especially in the Soviet Union, from the seventies on, and developed into studies on the essential similarities related to common tendencies toward a growing complexity, the growth of autonomy and progressive reliability.[3]

Ample and articled difusion was given, on the contrary, to studies developed in the field of bionics, where the simulation of vital processes has represented not an approach of a purely cognitive nature but rather an operative programme which allows translation of isomorphisms between organic evolution and technology into elements of design of the artificial.

At the basis of these diverse ambits of research, however, we can read that common methodology that consists in the fact of considering a biologic system to be examined as a prototype from which to derive a model which is successively interpreted in the project or in the study of an artificial system. The project or the interpretation thus derived do not have the intention of directly furnishing the resolutive phase of a possible technological advance. Actually, once individualized, a biological principle that seems useful only furnishes an orientating scheme, a kind of frame for the projective or conceptual solution. Afterwards, it is hoped that the successive developments and the increases in a specific direction will produce an autonomous system in relation to the original biological system from which one had parted. Biology, the first of the sciences to face the theme of design, offers in this sense an apparatus extraordinarily rich in conceptual instruments: morphological changes, information transmission, as well as the concepts of completeness, coherence, correlation and integration. The indispensable premise rests, naturally, on the knowledge of that part of biology from which the model is to be taken, to make a procedure possible that implies a series of successive phases: the selection of the biological system that can be investigated by virtue of the compatibility with its artificial analogue; the process of abstraction necessary to define the limits of the system investigated; the operation of translating by which the representation of the model is produced. From the last of these phases, therefore, it is possible to go to the interpretation of the model on the basis of the construction of a corresponding artificial system and, finally, to its verification. The analogical approach can also give place to positive retroactions in the system taken as a model and by extension in the disciplinary field to which it belongs, which, in its turn, can lend itself to new interpretations.

To the fields of comparison described till now —biology and technology— at least a third discipline has been added that has obtained, parting from a metaphoric construction, autonomous and relevant developments: economy. The use of the term «evolutive theory» applied to economic studies as an alternative to orthodox theories has been, in its turn, the sign that natural sciences can constitute sources of key concepts

1. Urbanek, A., «Morpho-Physiological Progress», in Nitecki, M. E., *Evolutionary Progress*, The University of Chicago Press, Chicago, 1988, p. 209.

2. Franz, V., «Zum jetzigen Stand der Theorie von biotechnischen Fortschritt a der Pflanzen und Tiergeschichte», *Biologia Generalis*, 19 : 3 (1935).

3. Cfr. Zavadski, K. M., «On the progress in living and technical systems», in Zavadski, K. M. and Meleschenko, Y. U. (eds.), *Theoretical Problems of Progressive Development in Living Nature and Technology*, Nauka, Leningrad, 1970, pp. 3-38.

common to diverse disciplinary fields, perpetuating an approach which has an antecedent in the contamination between the thinking of Malthus and Darwin. Fruitful contacts between biology and technology have set in motion elaborations that have invested as much the laws of technological mutation as the modes through which technological development leans on economic implications.[4]

In a position uncomfortably placed between the operativity of bionics and the formalization of «evolutionary» economic theories, we place the field of those speculative studies which, while they do not have the autonomy of a unitary corpus, can be reduced to the denomination of «technological Darwinism» a denomination that is surely not the index of the organicity of the theoretic contributions it gathers —quite heterogeneous on the other hand— but rather the common approach to the rereading, on the basis of the metaphor taken from the theory of evolution and taking from it new elements of knowledge, the way that objects and artificial systems evolve.

The meaning and some possible implications of this approach are the object of analysis of this paper.

Evolution and technology

In the construction of all possible analogies, and, therefore those that can exist between biology and technology, between evolution of the living and artificial evolution, we have said that it is necessary to have decided *a priori*, or maybe only to have intuited, that area beyond logic and experience where it seems licit to construct similarity.

Consequently, why is it possible to believe that the ambit of technological mutation can obtain an increase of knowledge from the analogy with a model, that of evolution, that comes from biology?

Some basic rules of comparison between biological evolution and technological change really evidence all its debatable aspects. A real intellectual trap, analogies of this kind offer, in Stephen Jay Gould's opinion, examples of effects more harmful than useful. «Biologic evolution —writes Gould— is a bad example of cultural change»,[5] and for reasons that could not be more radical: the rythm of cultural evolution has timings enormously and incomparably faster than any biological change; cultural evolution, in second place, is Lamarckian, with results from one generation that are transmitted directly to the next provoking that speed of change unknown to nature: biologic evolution is in fact indirect and Darwinian, and the favourable characteristics are transmitted to descendents only if they have been casually originated from genetic changes. Finally, biological evolution is a process of constant divergence; while the tree of culture can surely diverge in its ramifications, it can also converge, reunify, and recover reversible pasts.

Why therefore, in spite of these irresoluble differences that discourage more than stimulate comparison, does it seem not only possible but even profitable to recur to analogy?

The basic motivation rests on the recognition that as much cultural evolution, of which material culture forms part, as biological evolution are systems of historical change. Both are, as the root of the word «evolution» suggests, forms of deployment from which it is possible to interpret or reconstruct the order.

The comparison with biology and some of its principles formulated in the Darwinian theory and successive modern synthesis is not useful, therefore, for the explanation of technological change. What is demanded, at the most, is whether from the two different disciplinary fields, the two groups of information, it is possible to obtain profound elements common to the organization of both, so that it becomes possible to recognize the principles of general structure that are the basis of all systems that evolve historically, searching for the possible regularities that govern the laws of change, independently of the nature of the system considered.

There is no similarity, therefore, to be shown between organisms and machines, between natural and artificial systems. But in the light of contemporary advances of epistemologic studies on the general nature of change not only of biological but also of cultural systems, it is plausible to believe, as Gould writes,

> that, at the base of structurally similar systems that proceed by diverse evident rules, there are general principles. True unity does not reside in erroneous applications of these evident rules (such as natural selection)

4. See, for example, Di Bernardo, B. and Rullani, E., «Evoluzione: un nuovo paradigma per la teoria dell'impresa e del cambiamento tecnologico», *Economia e Politica Industriale*, 42, 1984, pp. 39-106.

5. Gould, S. J., «Il pollice del panda della tecnologia», in *Bravo Brontosauro*, Feltrinelli, Milan, 1992, p. 63.

to strange ambits (such as technological change), but rather in the search for more general rules of structure and change.[6]

Darwin among machines

The most widely quoted antecedent and obligatory reference for every study oriented toward the construction of an analogy between technological evolution and biological evolution are always the writings of Samuel Butler, an enthusiastic convert to Darwin's evolutionism who immediately became one of its major and most sarcastic critics, prefering positions closer to the theories of Jean-Baptiste Lamarck. In the long and tortuous road that saw him go from the first enthusiastic and convinced supporter of Darwinism to bitter opposer and devout Lamarckist, Butler expressed his position in the biological debate rereading technological evolution as an analogy of natural evolution.

Mainly grouped together in the 1872 novel *Erewhon*,[7] these ideas had been elaborated a decade before, and published in the form of the essays «Darwin among the Machines»[8] and «Lucubratio Ebria».[9] In the first there already appeared the more important elements of the literary metaphor between Darwin's theory of evolution and the evolution of machines: the introduction of the expressions «mechanical life, mechanical kingdom, mechanical world», recognized and sanctioned the autonomy of a universe that, like the animal and vegetable kingdoms, could lend itself to classification according to genera, subgenera, and species.

The recognition of a specific mechanical world in the image of nature also induced Butler to individuate a field of investigation where it would be possible to discover those intermediate links that tie together machines of diverse species; where it could be demonstrated that selection carried out by humanity develops the same function as natural selection; where the study of atrophied or useless mechanical organs could, in consequence, help to recognize the descendence from ancestral types passed on to a new phase of mechanical existence.[10]

The elements Butler drew from the theory of evolution to draw his metaphorical comparison were essentially configured from the possibility of genealogic reconstruction of diversification in the mechanical kingdom, from the existence of a selective mechanism applied by humanity that permits survival of the fittest in a Darwinian sense, and, finally, from the recognition of a concept of use and disuse —of Lamarckian fabrication— applicable to the evolution of artificial organs.

To these analogies is added the reference to comparison in morphological terms, individuated in the supposed progressive decrease in size which in a similar way would have accompanied the evolution of some invertebrates and the development of machines,[11] that overcame the apparent impossibility of comparing the reproductive capacity of living organisms.

The central theme elaborated in these essays —the development of technology— reappears in the chapters of *Erewhon*, where the theory of evolution is applied to the mechanical field with the ultimate aim of showing the evident absurdity of treating machines like organisms and, consequently, organisms like machines: an objective that constituted an implicit dependence on the mechanism which Butler recognized in Darwin's theory.

The point of departure of Butler's criticism is the conventional analogy between machines and organisms. In an observation which is even generic, both genera show, in fact, evident common properties: as much machines as plants as animals depend on external sources of energy; all of them regulate and control their activities; if living organisms alone seem capable of autonomous reproduction, it is true, however, that in some cases this only happens on the basis of the mediation of other organisms. If a true difference must be pointed out, this seems linked not to intrinsic properties but rather to the different speed at which organ-

6. *Ibid.*, p. 64.

7. Butler, S., *Erewhon*, London, 1872.

8. Cellarius, pseudonym of Butler, S., «Darwin among the Machines», *The Press*, Christchurch, New Zealand, 13 June 1863. Amplified and rewritten, the essay was republished later with the title of «The Mechanical Creation», *The Reasoner*, London, July 1885. The Italian translation to which I here refer is contained in *I classici Adelphi* 1963-64, Adelphi, Milan, 1964, pp. 141-150.

9. Butler, S., «Lucubratio Ebria», *The Press*, Christchurch, New Zealand, 29 July 1865.

10. Cfr. Butler, S., «Darwin e le macchine», *op. cit.*, p. 143.

11. «It is true that in our days there are already machines that are used to bring new machines into the world, and that become the parents of other machines, often of the same species» (Butler, S., «Darwin e le macchine», p. 148).

isms and machines evolve. The latter are, in fact, subject to a very fast evolution that can escape from the control of humanity, favouring —an expression beloved by Butler— machine supremacy.

Beyond Butler's irony and his criticism of evolutionism, a later theme, also elaborated in *Erewhon*, seems —in the light of contemporary vision— clearly anticipatory: the idea of the machine as an extracorporal organ, an artificial prolongation of physiological capacities. See, for example, how the analogy between tools and organs is developed according to Butler:

> See the man who digs with a plow: the straight forearm has become artificially prolonged and the hand has become a union. The hilt of the plow is like the protuberance that there is above the arm, the handle is an added bone, and the oblong iron blade is the new form the hand takes on, a form that allows its holder to turn over the earth in a way which would be impossible with his original hand.

And he adds: «A machine is only a suplementary organ; here you have the nature and the function of machines.»[12] The machine appears, therefore, as a superior phase of the development of humanity, whose overall evolution —in coherence with the positions assumed by Butler— eventually assumes markedly Lamarckian characteristics: the tools of humanity, extracorporeal organs, are developed at the same time as the biological organs, through decided efforts and not through blind chance. Use and disuse can also intervene in the definition of residual or rudimentary organs of which Butler did not cease to give significant, although limited, examples.

From the reading of Butler's metaphors, beyond their objectives and the meaning of the specific argument, there clearly emerge some themes that justify a first level of acceptability of an evolving reading extended to material culture. This is thus because of the vision of the supremacy of machines, or because of the idea of the development of manufacturing and machines according to a series of unfoldings of a successive order. The intuition of the continuum «man-arto-artificial» contributes to define a new perspective, where the classic metaphor of body as machine (which in its turn historically substituted the preceding image of body as metaphor of the cosmos) paradoxally loses its metaphorical integrity to gain a real consistency. The homologation of any object, any tool or artifact, to a prosthesis, to that which can substitute or potentiate the human organ, conceptually eliminates in fact the meaning of the metaphor: human body and extracorporal organs, unopposed, eventually share the same nature from the functional point of view.

The implications and advances that modernity offers to this perspective are well known: the prosthesis is expansive and substitutes miserable organs, as a witness of the history of medicine, or prolongs and potentiates the missing human organ, tends to copy and substitute codes and programmes, insinuating themselves more deeply into the life process.[13]

The classic darwinian analogy: trial and error

The model on which the conventional analogy of the evolution of manufacture is most often constructed originates from the three fundamental observations elaborated by Darwin in *The Origin of Species*.

The first reveals that

> every living being naturally propagates in such a rapid progression that, if no natural causes of destruction intervene, the Earth would soon be covered by the progeny of one single couple,[14]

and it is known how, from this observation (and the suggestion from the essay by Robert Malthus[15] where it was affirmed that human society grows at a more rapid rate than the means of survival available), Darwin drew that concept of «the struggle for existence» destined to become a principle of general order in his theory.

The second important observation in fact implies that between the individuals of diverse species there must take place a struggle for survival, as much in the form of competition of the young individuals to reach maturity as in the form of reproductive superiority.

12. Butler, S., *Erewhon*, Adelphi, Milan, 1965 and 1975, p. 198.

13. Cfr. Attali, J., *L'ordine Cannibale. Vita e morte della medicina*, Feltrinelli, Milan, 1980, p. 247.

14. Darwin, C., *L'origine delle specie*, Bollati Boringhieri, Turin, 1967, p. 133.

15. Malthus, R., *An Essay on the Principle of Population*, London, 1798.

The third observation draws, finally, the concept of variation: individuals present diverse characteristics, some beneficial in terms of struggle for survival, some unfavourable; individuals with advantages have in this sense more possibilities of reproducing and hereditally transmitting the favourable characteristics they possess, while the unfavourable modifications are destined to disappear.

Darwin's most relevant intuition was, however, that of transforming the differences between individuals in the ambit of a species to differences between species in space and time.[16] Therefore, due to the fact that evolutionary change represents the result of variation between species and the successive alterations in time, Darwin was able to describe a mechanics and kinetics of the transformation of variation, the principle of heredity and the principle of natural selection.[17]

These key concepts of Darwin's theory find a first and partial application in the field of material culture thanks to systematic studies of anthropological and archaeological nature about the modalities with which tools had been produced and developed in primitive cultures. An approach which, parting from schematic reconstructions of manufacture, is not lacking in very specific elaborations and hypotheses, such as the concept of the «orthogenesis of tools» formulated by Leroi-Gourhan, who, «struck by the analogy with some paleontologic evolutions», in this way admitted as a hypothesis a general technical fact.[18]

The variability of the products of human activity being universally recognized, a further step in the analogy between organic evolution and technological evolution consists of the identification of heredity with the copy.[19] Tools constitute in fact the copy of preceding models, assuring an exact reproduction of the types in the interior of some primitive societies, based on not only social stability, but also on forms of material production. This stability could constitute the equivalent in technological terms of the stability of form that genetic heredity confers. However, even in the stability of the sequences of primitive objects —and analogously with all that takes place with living organisms—, it is licit to expect the appearance of some small modification in the copies and to read variations which can be assimilated to those described by Darwin: that is to say, minimum modifications which, if they are able to confer an advantage, tend to be selected as favourable. Not even here is it necessary for all variations that arise in copies be favourable. Observes Steadman:

> It is possible that variations be introduced quite accidentally, by chance, and that it is the mechanism of selection that guarantees the diffusion of the favourable characteristic and the elimination of the unfavourable.[20]

This form of analogy applied to manufacture also introduces a specific reading of the relationship between the manufacture and the type, between the copy and the model.

If the type constitutes that which is effectively transmitted with the copy, it is licit to consider it as the group of genetic instructions transmitted. The analogy would suggest at the same time that as to the fact of manufacture we could speak of a process of transmission of information inherent to its function and production, informations that together define the «guide model» to which the artisan —we are still looking at pre-industrial societies— refers.

In this sense, it is not the concrete manufacture that evolves, but rather the abstract type to which specific manufacture corresponds. The distinction offered by biology between genotype, as a description of the species transmitted by biologic heredity, and phenotype, which physically specifies the genotype's information, offers the model of an analogous distinction between type and concrete manufacture, and introduces the theme of the difference between hereditary variations and environment-induced modifications. We must briefly remember how, in nature, the genotype, that is, the group of instructions constituted by the genes, is physically carried out by the phenotype, the process of development of the system of which is, however, flexible enough to support the direct environmental conditioners. Such induced variations are not, however, transmitted to descendents.

As to manufactures, it is analogously noticeable that even if an abstract type exists, an *a priori* form, it is possible to carry out diverse phenotypes on the ba-

16. Cfr. Lewontin, R. C., «Evoluzione», *Enciclopedia Einaudi*, vol. V, Einaudi, Turin, 1978, p. 1013.

17. *Ibid.*, p. 1014.

18. Cfr. Leroi-Gourhan, A., *Il gesto e la parola. Tecnica e linguaggio*, vol. I, Einaudi, Turin, 1977, p. 159.

19. Cfr. Steadman, P., *L'evoluzione del design. L'analogia biologica in architettura e nelle arti applicate*, Liguori, Naples, 1988, p. 112.

20. *Ibid.*

sis, for example, of locally available materials. Environmental factors, to quote Steadman,

> acting on the production or development of manufacture, will plausibly have as a consequence slight changes or variations in form between an object of a determined type and another. (If such variations can be «hereditary» in the case of technology, is a rather more complicated question.)[21]

Overcoming the doubt expressed by Philip Steadman, it is really essential that in the products of human activity —as compared to what happens in nature— modifications and variations induced by specific environmental conditions can be directly inherited by the products of succeeding generations.

From the general principles of Darwinian theory there still remains to be considered the true nucleus, that principle of natural selection which flows together in the process of trial and error, where trials (variability) are assured by the appearance of variation, and errors (the unfit) are eliminated. The metaphoric application of the concept of selection illuminates its double usefulness as a conceptual tool: on the one hand, it develops the conventional role in light of the function of intentional choice carried out by humanity or by the markets to the products of its activity; on the other, it opens up a perspective that Steadman defines as an ecological analogy,[22] capable of reading the progressive «adaption» of manufactures operating on the scale of interrelationships between form, function, and environment.

A natural history of manufactures

In the diverse approaches initially interlaced in Samuel Butler's metaphors, Herbert Spencer's first classifications of anthropological studies and suggestions, the centrality of manufacture as a primary unit of the evolution of technology remains unaltered.

It is possible in this sense to recognize that a part of the contributions in the direction of *technological Darwinism* converges at first with a vein —destined to renew itself in time— which draws the evolution of the products of human activity as a genealogic reconstruction of the families of manufactures, where these have the same importance as plants and animals in organic evolution.[23]

Natural history appears in this sense as the source from which to obtain a method or system to classify genera, species and varieties, that can lend itself to ordering manufactures from correlative forms.

The sequence from simple to complex, from homogeneous to heterogeneous is recognized nowadays as the informing principle of the scale of material progress. The oldest manufactures and their descendents can in this way be ordered in progressive and continuous series that make the evolution of culture visible, from primitive states to the highest forms of civilization.

The Pitt-Rivers collection of manufactures[24] constitutes one of the first examples of the scientific organization of the classification of a group of manufactures according to an evolutionary scheme.

Possibly inspired by the ethnographic exhibitions for the Great Exhibition, Pitt-Rivers had the original idea of a collection of tools, instruments and invention towards 1852, when he was charged with experimenting with new models of rifles for the British Army, and preparing an instruction manual. While he was examining the historical development of modern arms, Pitt-Rivers concentrated on the gradualness and slowness of the process of perfection, concentrated on small advances in yield and minimum modifications in the joint organization of components. From this came the idea that analogous principles could govern the development of other manufactures, and then his interest for collecting and classifying, to furnish a reconstruction of their relationships and their historical origins.

As in the organisms studied by natural history, so in relation to manufactures the problem of the missing links was proposed and the difficulty to establish in what measure an object was ideal for insertion in a sequence. Among the greatest criticisms of the theory of evolution, that which referred to evident gaps of intermediate forms between existing species constituted from the beginning a critical point which Darwin himself had anticipated in *The Origin of Species* analyzing the imperfection of geologic documentation.[25]

21. *Ibid.*, pp. 113-114.
22. Steadman, P., *op. cit.*, p. 89.
23. Cfr. Basalla, G., *L'evoluzione della tecnologia. Cause, modalità e effeti del progresso tecnologico*, Rizzoli, Milan, 1991, p. 49.
24. Cfr. Pitt-Rivers, Augustus-Henry (Lane Fox), *The Evolution of Culture and Other Essays*, Oxford, 1906.
25. Darwin, C., *op. cit.*, p. 371.

In any case, it was still an essential premise that nature does not jump, that the progress of evolution is always gradual and proceeds by small improvements. Pitt-Rivers estimated that this same gradual evolution is verified in primitive manufacture, and that only the disappearance of the intermediate forms, as in the extinction of transition species of animals or vegetables, gave the false impression of objects «invented» separately and independently.[26] Analogously, modern inventions lent themselves to interpretations as the result of an evolution by small phases, traceable as much in intermediate stages of thought process as in phases of experimentation.

Form is in any case the principal order in Pitt-Rivers' sequences, where tools are shown in in a correlative succession organized on the basis of formal deviations, imperceptible or perceptible. The image that derives from this —at least as to primitive manufactures— is that of a slow succession, of a formation of sequences which —without a preconceived design— suffer a process of selection applied by humanity, capable of carrying out more suitable manufactures for specific ends, of discarding the less fit, of gradually modifying the «survivors». In the progressive variation of objects and in the possibility of reconstructing their history there is, even here, an implicit interpretation of the unity of change, which is destined in time to be the object of controversies as much in biology as in technology.[27]

Beyond the enthusiastic adherence to the idea of the evolution of manufactures, Pitt-Rivers' work shows the evident limits of a reductive use of the theory of evolution, which ends up confined to a «paleontologic» reconstruction of some types of tools. At the same time, these studies develop a positive function, offering an original concept destined to last: after having overcome the classifying fever that there is at the base of the many taxonomies of objects, what remains is, in the end, the recognition of a statute of the existence of manufactures, which, from inert entities that respond to need, becomes a significant phase of a sequence that can be retroactively covered step by step, toward the genesis of manufacture itself.

Genetics of the industrial object

Almost a century after Pitt-Rivers' classification, that which can be defined as a genetics of industrial products has taken shape in the work of Yves Deforge, where the comprehension of the industrial object comes from the approach of an evolutionary dimension that becomes the essential condition for a reflection on industrial techniques and on the products derived from them.[28]

Contrary to most analogies used till then, for Deforge the integration of the concept of evolution takes place through the development of real, if rudimentary, operative instruments: the notion of genetic descendence, of the law of evolution, of the networks of relationships of the object with the system of which it forms a part.

The genetic descent of the industrial object seems to be made up of objects which have the same function or use and which practice the same «principle». For this latter a specific definition has been introduced, that is, *technologic essence*, which is manifested through solutions and forms that make it appear between the expression of the problem and the achieved solution.[29] The constituting principle of a genetic line can consequently be individuated in a patent of invention or —more freely— in a type, even if the base never ceases to be the physico-chemical phenomenon activated by the object itself. For the automobile, for example, the principle that founds a descendence could be a stable type, or a fundamental component such as the engine and its modes of functioning, or even a structural characteristic. Once this principle has been established, the genealogic line is presented as a chronologic order of objects that share a same use. From the origin of a line to its abandonment or interruption, the objects that form a part of it follow a succession which goes in the direction of successive improvements. These improvements which are introduced in the environment of artificial objects are

26. Cfr. Steadman, P., *op. cit.*, p. 124.

27. Cfr. Balfour, H., introduction to Pitt-Rivers, A., *op. cit.*, pp. VII-VIII.

28. Deforge, Y., *Technologie et génétique de l'objet industriel*, Maloine, Paris, 1985.

29. *Ibid.*, p. 101.

> a sort of formalism, by which advances and regressions, convergences and divergences of the lines would be no more than micro-evolutions in a line of general evolution.[30]

A second conceptual instrument formulated by Deforge, the laws of evolution, refers to the existence of many descendencies evolved from industrial objects, whose solutions constitute examples of progressive autonomy and concretion. The introduction of the latter term is directly related to the process of «from abstract to concrete» elaborated by Gilbert Simondon in the analysis of the evolution of technical objects. In Simondon's formulation, the technical object progresses toward solutions in which functions enter into a mutual relationship, they complement one another, they fuse together, till they constitute a group of forms and functions oriented toward a total integration, toward a progressive closure of the system they make up.

Besides their progressive integration, objects also present an increase in autonomy of function which is translated into a tendency to auto-regulation —in strict analogy with living organisms— to be understood as a capacity to respond to internal and external upheavals, to the improvement in physical relationships between parts, and even to a relative capacity for autosufficiency which «naturalizes» the object, which can show itself to be able to autonomously produce energy for functioning, or to repair itself. Evolution from the primitive form of the technical object, the abstract form in a word, to the concrete form, allow us to enounce laws —along with Simondon— that, as we have seen, describe a process that moves in the direction of the reduction of dimensions, of energetic autonomy.[31] Deforge reconduces the same evolutionary laws of self-sufficiency, of self-regulation, and of correlation of parts toward a more general concept of «self-adaptation»,[32] where the image of an integrated unit made up of both the industrial object and its environment take form.

A third conceptual tool introduced by Deforge responds to the fact of the need of reconstruction —in a specific phase of the evolution of an industrial object— the network of relationships which that object establishes with its environment, that is to say the wider environment of which the production, consumer, and use system form part. A point of view and a method that are proper to the study of phenomena that extend over long periods of time and help to define the *milieu associé* of the phenomenon under consideration,[33] which in this case is configured like the network of the reciprocal relationships that the object carries out with each subsystem of the wider industrial system. If, of the instruments proposed by Deforge, the two first admit a diachronic and synchronic vision of the evolution of the descendents of industrial products (which appear as the result as much of the context of which they form a part as of a genetic continuum), it is, however, the latter which, with the hypothesis of the reconstruction of the environment associated with the object, prefigures the development of a systematic view. And if this global perspective remains —in Deforge's study— really only sketched out, at least the points of view begin to multiply, so that products and their genealogies evolve in the interior of a production system, machines in a system of use, objects in a consumer system, thus drawing the partial and multiple readings destined, on the basis of contemporary or later theoretic contributions, to flow together into a unitary vision of systematic approaches.

From the demography of objects to technical species

In the construction hypothesis of a theory of objects with a sociologic nature, Abraham Moles introduced a few decades ago the concept of «demography of objects», in the etymological sense of the description of populations and their relative variations. Inside a classificatory approach to objects, on the basis of a willingly forced analogy, species and subspecies, rates of birth and aging of products are prefigured, till we arrive at a possible approach between the idea of object maintenance and preventive medicine.[34] The character-

30. *Ibid.*, p. 72.

31. See the first chapter of Simondon's, G., classic work *Du mode d'existence des objets techniques*, Aubier Montaigne, Paris, 1969.

32. Cfr. Deforge, Y., «Simondon et les questions vives de l'actualité», epilogue to Simondon, G., *op. cit.*, ed. 1989, p. 284.

33. The term *milieu associé* has its definite introduction by Simondon, G., *op. cit.*, p. 57.

34. Cfr. Moles, A., «Objet et communication», in AA.VV., *Les objets. Communication*, n. 13, Éditions du Seuil, Paris, 1969, p. 11 (special translation «Objeto y comunicación», in *Comunicaciones. Los objetos*, Tiempo Contemporáneo, Buenos Aires, 1971).

istics of a demography of artificial products drawn by Moles, and of the implicit possible classification methods,[35] already led to at least two kinds of useful considerations for a systematic interpretation: in the first place the introduction itself of the idea of demography prefigured an ecological opening, in the sense of a discipline that considers the balance of species, of their relationships, of the modifications of some in respect to others. From this point of view, populations of objects seemed an unlimited field of analysis for an approach with interdisciplinary instruments. In the second place, those same populations presented —even for a superficial observer— a problem unknown to traditional ecology: that is to say, the continuous and accelerated appearance of new artificial species, as a counterpoint to the relative fixity of living species.

The classificatory meaning that Moles wished to give to artificial species is at least lined up with another definition formulated in those same years. The concept of «technical species», elaborated in Gilbert Simondon's classic work,[36] which uses a terminological repertory taken from the field of biology to construct —in the line of analogy, but with complete disciplinary autonomy— modes through which the technical object defines its status of existence.

The technical species in this sense defines a first and summary distinction between objects on the basis of their practical purpose, a distinction which according to Simondon gives an illusory specificity,[37] given that use joins very diverse structures and uses.

If the individuality of the technical object described by Simondon, the specificity in the sense of belonging to a species, shows itself as unstable, that firmly reaffirms the idea that every technical object is defined through its genesis.[38] The reading of Simondon has the merit of allowing a liberation of the conventional sense of belonging to a species which precedes the classificating operation. The use of what is called a genetic method has, in fact, the primary objective of avoiding the use of a classifying model that otherwise would intervene after the genesis of objects to distribute them all in genera and species.

On the contrary, the technical object is seen in the dynamic dimension of its evolution: as in a philo-genetic line, the object contains in itself structures and schemes that determine its successive developments. The evolution prefigured by Simondon's analysis moves in the direction of few specific types, which are the result of a process of differentiation and of progressive organization. But like all evolution, this one also exposes the problem of the absolute origin, which in Simondon's examination takes the form of a specific technical reality. The absolute beginning is thus re-led to an act of invention. The origin of a descent of technical objects is marked by a synthetic act of invention which originates a *technical essence*.[39] This essence is recognizable by its stability in a line that evolves and by its capacity for the production of structures and forms by «progressive saturation». The primitive technical object is in fact compared to a non-saturated system whose successive improvements make up the phases towards saturation of the whole: from this comes the image of the object as a possessor of «fertility» proper of a «non-saturation» that allows it to accede to posterity. If the object appears to suffer changes and alterations of its exterior, these are really the phases of a progression which gives form to a family which has as its progenitor the primitive technical object. An evolution that in this way seems definable as a «natural technical evolution».[40]

Technical kingdom and techno-evolution

Gilbert Hottois, on the contrary, has introduced the specificity of technique as a «kingdom»,[41] observing its intrinsic tendency to constitute itself into an autartic environment, isolated and contemporaneously oriented toward the proliferation and assimilation of that which surrounds it. If it is true that technique tends to be substituted in some parts of the natural ecosystem into which it inserts itself, if the universality of the technical environment is able to produce the image of another nature,[42] it seems licit to define its environment as a kingdom, in the image of the animal and vegetable kingdoms.

35. *Ibid.*, p. 10.
36. Simondon, G., *Du mode d'existence des objets techniques*, *op. cit.*
37. *Ibid.*, p. 19.
38. *Ibid.*, p. 20.
39. *Ibid.*, p. 43.
40. *Ibid.*
41. Cfr. Hottois, G., *Le signe et la technique. La philosophie a l'épreuve de la technique*, Aubier Montaigne, Paris, 1984, p. 120.
42. Cfr. Ellul, J., *Le système technicien*, Calman-Lévy, Paris, 1977, p. 350.

The use of the term «kingdom» is not used here to define limits, but rather to evoke an image of organic homogeneity, of specificity, of growth dynamics, autonomy and difference, where technique is recognizable. The autonomy of the technical kingdom is not synonymous with absence of interchange with other kingdoms, rather the contrary: the confrontation of bio-evolution with *techno-evolution*[43] can show itself to be clarifying.

At a first level, the analogy between the two forms of evolution seems based on intuited common traits: the morphologic continuity that incorporates novelties and perpetuates the old forms (the evolution of a species would correspond in this case to the appearance of manufactures); the occupation of ecological niches according to a systematic sense which is applicable as much to life as to technique (if on the one hand it is possible to assist at the survival of a living species in the appropriate micro-habitat, on the other a technical species is only conceivable inside infrastructures that assure its reproductive processes, conservation, and nourishment); a general principle of the struggle for survival (in which the fittest imposes itself in the biologic as well as the technologic world); the tendency to morphophilia, that is to say, the extraordinary abundance of forms, of interspecies variations, is not always justified by the demands of function and adaptation; the abundance of creations which do not always find an application (on the one hand the unfavourable or recessive variations, on the other patents); the combining nature of innovations (which as much in biology as in technology can reorganize everything that already exists); the presence of periods of stability and evolutionary balance, the sudden discontinuities and mutation bounds (the step to a new theoretic system or the appearance of a new species of technical objects); finally, the idea of evolution as a process that becomes progressively more complex.[44]

What perspectives does an analogic procedure of this type open up?

Gilbert Hottois formulates the hypothesis from multiple reading plans. In the first place, following the tracks of the hypothesis of a zoological origin, so to say, of technique, as that formulated by Leroi-Gourhan,[45] it is possible to sink the roots of the appearance of technique in bio-evolution itself, from which would be drawn a continuity of principle between the natural and the artificial. In second place, formal resemblances allow the reconstruction of the stages of techno-evolution assimilable by analogy to bio-evolution.

Finally, it seems legitimate to formulate the hypothesis that transformations which technique can introduce are susceptible of acquiring a mutational and properly evolutionary nature, completely different from the continuity implicit in cultural and historical transformations.[46] The evolutionary perspective in this sense invites an introduction of a category of discontinuity, of distance, of strangeness —proper, exactly, of the concept of mutation taken from biology— which, as Gilbert Hottois observes, shows itself to be deeper than any historical hiatus.[47] In this sense, the history of techniques does not seem to have ever known discontinuity and the deep sense of fracture that mutation implies.

Contemporaneously, the same evolutionary perspective is opposed to a conception of technical growth as a string of accurate, monolithic, almost «insular» innovations, as Hottois defines them. The view that the technical process provokes is, therefore, a complex one: growth becomes a «combining proliferation that acts in very sense», where every new invention is placed on a crossroads of many technical vectors, where each expantion is fruit of forces and potentials that belong to the technical environment on the whole. A process that can be assimilated to a form of almost spontaneous self-growth, product of a proliferating combination, «chance and causal at the same time»,[48] which proposes the image of a *physis* and points at the profound diversity of this view of the technical kingdom compared to traditional concepts, anchored in the creative dynamism of individual subjectivity.

43. The term «techno-evolution» has been introduced by Lem, S., *Summa Technologiae*, Insel, Frankfurt amb Main, 1976.

44. Cfr. Hottois, G., *op. cit.*, pp. 29 and succs.

45. In the first appearance of tools and manufactures it is possible to read a direct prolongation of the morphologic evolution and biologic functions. See Leroi-Gourhan, A., *op. cit.*

46. Hottois, G., *op. cit.*, p. 132.

47. *Ibid.*, p. 135.

48. Cfr. Ellul, J., *op. cit.*, pp. 229-248.

Towards a neo-darwinian sense of «technology»

The concept of technology itself, to be understood as the set of a population of material and non-material systems, has been placed in a neo-Darwinian perspective, the theoric bases of which are represented by the synthesis of the graduality and discontinuity of evolution.

Technology shows itself to be particularly adapted to these applications, above all if it is understood, as Luciano Gallino writes,

> as a set of organs, and more analytically of traits, properties or characteristics, subject to continuous variations which are accepted or transmitted in differential form by human populations.[49]

Gallino's interpretation proposes in this sense that each technologic system and its successive replicas, are gradually modified in time, so that at a given moment a technologic «population» will present a distribution of variants different from the preceding moments: that which Darwinially is understood by evolution and which in modern synthesis is defined as a micro-evolution. In no way is it missing from this reading the possibility that systems could appear, capable of introducing structurally new processes and functions: «it is the equivalent —writes Gallino— of the typologic leaps of the living being which are defined as macro-evolution, and there are good reasons to believe that they are not derivable from micro-evolution».[50] A phenomenon, that of the leap, destined to give place to technologic systems which, although they obey the logic of survival of the fittest, can substitute precedents but also coexist with them, creating complementary positions.

The reading of Gallino shows how the recourse to an evolutionary model (in which classic Darwinian thinking converges with the elements of modern synthesis) for the interpretation of non-biologic phenomena can go beyond the heuristic sense of metaphoric procedure to open up to the wider perspective of the co-evolutionary vision which sees biology, technology, and social and cultural processes as links of a general evolution.

The transposal, proposed by Gallino himself, of the concept of «biologic idoneity» to the field of technology represents a later development of this focus.

In the definition formulated by Medawar,[51] idoneity in biology is configured as a combined function that includes as much the survival of an individual as the multiplication of the offspring. This means that the longer an individual survives, the wider its period of potential for reproduction. Every element —functional, morphologic or adaptive— destined to make the idoneity of an individual or a population row, can constitute an adaptation that can be transmitted to descendents or that can be lost. Completely new traits can also appear in a population. Consequently, «a population that exhibits a distribution of significantly variant traits compared to the population from which it descends, will have suffered an evolution».[52]

An analogous logic seems applicable to technologic systems, considering that the contemporary ones descend from preceding ones and presumably make up the progenitors of future ones, and that these systems will contribute in a more relevant way than others to future developments. In this sense, an analogous concept of technologic idoneity is applicable, which implies an interaction of three orders of populations: human organisms, technologic systems and socio-cultural systems, in a co-evolutionary circuit where human populations influence the idoneity of technologic systems and, through these, on biologic and socio-cultural evolution. As Gallino writes,

> organisms of the first order (human beings) selectively use organisms of the second (technologic systems) to reproduce themselves and to reproduce organisms of the third order (socio-cultural systems) [...]; acting thus, they accelerate the evolution of technologic systems and their dependence on these, with long-term effects on their own probability of collective survival. This circuit has not till now been the product of an intentional design, nor are there signs that it is becoming so; more likely it is the emerging product of innumerable sequences of individual choices. Through their technologic choices, each social actor joins in determining the future of its species.[53]

49. Gallino, L., *L'attore sociale. Biologia, cultura e intelligenza artificiale*, Einaudi, Turin, 1987, p. 181.
50. *Ibid.*, p. 182.
51. Medawar, P. B., «The Meaning of Fitness and the Future of Man», in Cohen, Y. A., *Man in Adaptation. The Biological Background*, Aldine Chicago, 1974, 2nd ed., pp. 30-40.
52. Cfr. Gallino, L., *op. cit.*, p. 185.
53. *Ibid.*, p. 186.

The technologic populations that will descend from the contemporary ones will be the result of these choices, carried out in a relationship between technology and society which «goes through states of intermittent balance»[54] in the process of co-evolution between biology and culture. The states of balance can be described as stages of an evolution of which it can be said that it proceeds by successive *appearances* of technologic populations. To affirm that a preceding technologic stage makes the succeeding one possible without forming it means also to recognize a certain degree of discontinuity —and with it a possible mutational characteristic— traditionally lacking from any historic reconstruction of technologic change. The idea of the appearance, however, is linked to that of integration, because the appearance of a technologic population does not necessarily imply the disappearance of the preceding one.

An insuperable distance separates this systematic reading of technologic evolution from the literary metaphors and genealogic reconstructions of objects. There is, however, a point of contact toward which, in different scale, the phenomena studied seem to converge.

When Samuel Butler, «almost frightened by the immense development reached by the mechanical kingdom»,[55] prefigured machines parents of other machines, machines directed to supremacy, autonomous machines, he anticipated with eighteenth-century literary emphasis this vision of technology as a self-distancing system which modernity faces in all its extensions. «It may be that never —writes Gallino today, prefiguring the same image as Butler— did technologic systems operate among us expressing a conscience and will of their own»,[56] but apart from the metaphors and in the light of co-evolutionary dynamics, the same systems seem in such cases to evolve mainly in function of «their» reproductive interests and not those of the biologic and socio-cultural systems of which they are an integrating part. The dependence of human systems on technology goes so far as to assign as Gallino writes, «an absolute priority to the maintenance of the conditions of survival of technologic systems». Thus it can claim to impose on individuals and groups behaviours which diminish their biologic and cultural idoneity (thus defined as a gigantic *entropic mechanism*, which on one hand constantly introduces novelties which are self-organizing, and on the other substracts flexibility and impoverishes the wider system of which it forms a part) end up being no more controlable on the whole, as if they depended on autonomous propulsive dynamics.[57]

The morphogenetic nature of innovation

The adoption of an evolutionary paradigm for the study of not only mechanisms of technologic change, but also of the economic-industrial system on the whole, is in its turn motivated by wide-ranging reasons: industrial capitalism has been, in fact, considered as an intrinsically evolutionary system,[58] capable of containing the elements and forces of a self-propelling change which can modify as much technologic systems as economic and cultural meshes.

In the hypothesis of an evolutionary theory of industrial production, the rereading of the innovative process plays a basic role: if in fact the possible *genetic* processes of the new can have an origin, as traditionally understood, in economic demands or objectives, it is also true, however, that this happens inside a «multicausal» web of events.

> The new —it has been observed— is definitely not produced in the obsolete laboratory of the theory of the traditional company, where the causes of economic change are always exogenous and where adaptation to these exterior impulses takes place with purely endogamous variables.[59]

Overcoming the traditional concept based on exogenous variables (as a cause of change) and endogenous variables (effects) has been produced by admitting a systematic conception of industrial production and the environment in which it operates. In this context, change takes place in relation to economic and non-economic impulses, and, therefore, gives shape to economic and non-economic effects, without altering the system as a whole.

But the step from a systematic concept of the industrial system to an evolutionary concept goes further

54. *Ibid.*, p. 191.
55. Butler, S., «Darwin e le macchine», *op. cit.*, p. 142.
56. Gallino, L., *op. cit.*, p. 207.
57. *Ibid.*
58. Di Bernardo, E. and Rullani, E., *op. cit.*, p. 43.
59. *Ibid.*, p. 47.

and implies the recognition of an innovative process which

> does not reproduce the system *per se*, without varying structures, the rules of behaviour, and the values proper to the systematic mesh at a given moment, but rather acts as an element of change of the system itself, the «production» of the identity of the system at different moments.[60]

In the framework of research and experimental analysis on the economy of new technologies,[61] specific individual elements have already been highlighted which can join together for the formulation of a theory of innovation on the model of the evolutionary paradigm. For example, the concept of «morphogenesis» has been introduced, as a production of complex forms (complex innovations) that are differentiated as much from precise traditional innovations as from processes of transition. By morphogenesis we are to understand in this case the capacity of a system to create new structural forms in its interior. In the evolutionary concept, therefore, change constitutes not so much a disturbance of structures that remain unvariable as one that is present as a resource of the system itself.

In this sense, the term «evolution» becomes synonymous with the web of connections that links precise innovations and processes of transition, carrying out new systematic forms in the technologic field. From this comes the morphogenetic function, precisely as the production of new orders.

Contrary, therefore, to innovations that do not change the system as a whole, and the processes that, although complex, «design changes that begin and end without giving continuity to change»,[62] the true object of analysis of an evolutionary theory of technologic change is drawn in a new type of innovation, which represents a complex process capable of organizing macro-mutations. In close analogy with natural science, concrete innovations appear in this way linked by an evolutionary design which allows for the accumulation of micro-mutations, which, in their turn, produce complex forms that are reaffirmed as substitutes of those which preceded them.[63]

60. *Ibid.*, p. 49.
61. *Ibid.*, p. 52.
62. *Ibid.*
63. «It is this process —underline Di Bernardo and Rullani— which has evolutionary value and which represents an object of study different from the traditional theory of the company and that used in more usual theories about innovation» (*ibid.*, p. 58).