REMARKS ON THE DEVELOPMENT OF CYBERNETICS

Settimo Termini

Received April 7, 2006

Abstract. In the present paper a few aspects of the historical development of Cybernetics will be discussed. The aim is to show that by examining the epistemological problems behind these aspects of its development, we can acquire some useful tools for a better understanding of the current state of some of the theories and disciplines, related to information processing, which evolved out of that explosion of innovative ideas and which in the 1950s, combined and gave rise to the birth of novel and interesting paths of investigation.

1 Focusing the problem

The thesis presented and discussed in this paper is as follows. In the middle of the last century a few scientific fields of investigation which dealt (in various ways and in different degrees) with the processing of information raised an enormous number of challenging and innovative problems as far as accepted scientific tradition was concerned. At the same time (and this is the paradox which is worthwhile investigating) all the results that emerged from these investigations were unable to manifest themselves as a consolidated whole, that is, to present themselves in an organized, unitary way which would legitimize the birth of a "single", scientific discipline, with its specific features, methods and results, that would clearly differentiate it from other mainstream disciplines. This situation - common to a set of interestingly different investigations that took place under differing names - is, in our opinion, paradigmatically reflected in the development of Cybernetics (an early analysis of this problem can be found in [14])

One peculiar feature is the following. If we look at individual and innovative results which emerged from under the heading of Cybernetics, we can see that they can also be seen as results that could equally pertain to other disciplines. Thus, it seemed that this new science was able to trigger the "production" of new results, but once produced, these could be seen as belonging to more traditional fields of investigation. One example is supplied by Kleene's theorem on regular languages. We could then choose to move to a more abstract level, in an attempt to define how a general, research program of Cybernetics might be defined. The statement of a research program at a very general level clashes with the fact that no results will be obtainable, given this level of generality (and to the initial objectives).

Furthermore, if we look at the historical development of other associated disciplines,such as AI, Computer Science and General System Theory as well as Cognitive Sciences, we see that the same strange pattern of behavior is also visible in them. One of the most innovative demands of Cybernetics is to require scientific approbation for notions which had not been previously accepted in the scientific milieu. What was affirmed by John von Neumann, for instance, may appear surprising at the least (on a superficial level) if one remembers that it is a commonplace to see science as an endeavour capable of transforming inexact problems and notions into those which are more precisely defined:

2000 *Mathematics Subject Classification.* 68T01, 92B20, 92B05.
Key words and phrases. Cybernetics, Information, Interdisciplinarity, Explicatum, Explicandum, Vagueness.

> "The subject matter is the role of error in logics, or in the physical implementation of logics in automata synthesis. Error is viewed, therefore, not as an extraneous and misdirected or misdirecting accident, but as an essential part of the process under consideration". [21] [pag. 329].

And it is again von Neumann who presents complexity as a novel scientific notion, capable of delineating a new class of systems:

> "The discussion so far has shown that high complexity plays an important role in any theoretical effort relating to automata and that this concept, in spite of its prima facie quantitative character, may in fact stand for something qualitative for a matter of principle".

There seems to emerge a substantial connection between these central ideas grown within the Cybernetics program and some of the main goals of General System Theory, AI and Cognitive Sciences. At the same time, however, it seems difficult to give a precise characterization of the role played by Cybernetics. Indeed, one has to consider both its innovative program and the fact that it faded away rather quickly after being, initially, at the forefront of scientific discipline. Although Cybernetics was quite relevant at the inception of some new disciplines (such as Automata Theory) it is hard to point out any specific results which could be accepted for their high level of generality and, at the same time, be seen as being closely linked to their domain of reference. Automata Theory is a perfect example of this and in fact, would not, at that time, have been conceived and developed without the cultural context and interdisciplinary debate regarding comparisons between computing models etc. Even when Kleene had characterized what a network is capable of doing, thus founding Automata Theory, the results themselves and their subsequent developments were seen as results having more to do with algebra and no longer as a theorem, a principle or a 'law'of Cybernetics. Roughly speaking, two main problems will be dealt with in the following pages. The first problem concerns the unifying role advocated by Cybernetics with respect to several different phenomena. The second problem concerns the substantial use one finds in Cybernetics of such general (and also appealing) notions such as complexity and information. These remarks lead us to the kernel of the original Cybernetics program in its attempt to build a unified (and unifying) theory, capable of including new notions (information, complexity, feedback, interdisciplinarity, etc.) and general enough to be applicable to all systems where such notions are used independently from the specific features of the given systems. In other words, we may identify Cybernetics by a level of informational description which is able to account satisfactorily both for new notions and for a unified treatment of systems of different types.

Before discussing these points in the next sections, let us now summarize our thesis.

1. - In the Forties and Fifties of the last century, Cybernetics acted as a sort of catalyst indicating that many interesting and new ideas, concepts, formalisms which were moving in a very creative albeit disordered way, breaking the boundaries of traditional disciplines, could be seen as parts of a unique, new scientific discipline and not only as scattered (though very interesting) results. This new scientific discipline, i.e. Cybernetics (according to the definition and scientific work of Norbert Wiener as well as on the basis of the social acceptance of the scientific community of the time), moved along the lines of "classical" science; in the sense that it could also be seen as part of physics despite being devoted to the investigation of new domains with their very peculiar features[1] and notwithstanding

[1]That Cybernetics could (and also must) be seen as a classical science (not methodologically different from physics) to be applied to new domains of investigation was certainly Wiener's point of view. And the fact that it could be seen as part of physics, is the way in which it was received in Italy in the

its strong innovative points with respect to the classical scientific tradition. What are the consequences of Wiener's challenge? At first sight, extremely positive in the sense that all the scattered effort and results can be seen as parts of a unique and unitary effort. All the different results converge in reinforcing each other and all the interdisciplinary work can be seen as part of a large and important effort which did not need to feed off the "goodwill" of one of the traditional disciplines which were so "liberal" as to allow such unusual work to be carried out.

2. - This fortuitous situation, however, did not last long. Subsequently, due also perhaps, to questions of funding and to balance of academic power issues, some (natural) weaknesses in the new approach were used against Cybernetics being affirmed as the sole and unitary repository of the interdisciplinary work done in those years. And so, starting from the early Sixties the name Cybernetics itself started to become less fashionable than it had been before[2].

This evolution can be analyzed by taking into account the comparison between the general aims and objectives of this new discipline and the strength of the available formal tools and the obtained results. When there was strong divarication between aims and (general) results, Cybernetics as a unifying paradigm went through a critical period[3].

3. - From an epistemological point of view, the process outlined above, underlying the development of Cybernetics can also be used for studying what has happened to other interesting "pieces" from the information sciences. The problem of the formalization of uncertainty and vagueness is such an example[4].

2 New concepts *vs* unifying tools

It may be reasonably maintained that Cybernetics started as a unifying program for several, different trends of research. It can be properly characterized as an attempt to give

Fifties/early Sixties. This was certainly the vision of Caianiello, who did not see any substantial difference from the methodological point of view as well as from the general attitude to be taken in affording these new problems in studying traditional physical topics or, i.e., the neural nets (see, for instance, [3, 4]). It is certainly true that problems of funding played a very important role in the struggle between the so-called "symbolic paradigm" of A.I. and neural nets approach and it is also true that partial and provisional scientific results were used in a very unscrupulous way when each of the contenders wanted to defend the interests of his own paradigm.

[2]As regards the fact of "Cybernetics" either being no longer fashionable or being seen in a bad light, I shall limit myself here to mentioning only two facts. Firstly, at the beginning of the Sixties, the term "Cybernetics" not only tended to be avoided in the United States in new initiatives, but some other strange things also happened. For instance, the title of the Russian journal "*Problems of Cybernetics*" is literally translated into English in the years 1961, 1962 and 1963, while in 1964 it appears in English as "*Problems of System Sciences*", even though the original Russian title had not changed at all. (Incidentally, it would be interesting to reconstruct the fate of Cybernetics in the former Soviet Union as it followed a different - but also tortuous - path). Secondly, it is interesting to observe that the renowned journal "*Kybernetik*" changed its name a few years later into "*Biological Cybernetics*" seeking maybe a more specific identity.

[3]It is also true that Cybernetics either in Wiener's original formulation or in any other reasonable variant that could be envisaged at the time was not powerful and general enough for it to present, in a unitary way, all the developments that were emerging in the course of a very creative period in that period. So, in a sense, we could speak of a "Rise and Fall of Cybernetics", by which we mean, the rise and fall of a unique paradigm, able to unify, or at least to present in a unified way all the scientific results which were fruitfully emerging (see [5]). In addition, interdisciplinarity too, that had played such an important role in the early years, began to assume less importance as this new sector began to accumulate interesting results without making further new contacts with different disciplines. This is the case, for instance, of Automata theory, which after its first very important mathematical characterization results (mainly Kleene's theorem) proceeds without any contact with the modeling of neural nets from which it originated. The same process, in my view, can be traced and recognized in the development of other fields of investigation.

[4]In the huge setting of analyses of this interesting problem, see [6, 7] for a technical proposal of controlling fuzziness. The difficulty of grasping vagueness in general into a working formal scheme is evident, for instance, in [2, 13, 15, 16, 19]

an interdisciplinary and unifying treatment of common aspects for several classes of complex systems (from sophisticated technology to the most complex system of the biological domain, i.e. the brain). At the root of such an attempt was the belief that a variety of feedback mechanisms, which are found in systems and organisms of a wide-ranging nature, ought to be guided by the same set of laws, independently from the specific function they have in any such system. This program was bound to face setbacks. When properties of such apparently similar phenomena were carefully investigated, people realized that the context in which these phenomena occur (that is, the particular type of system) influences the criteria according through which the study and solution of the same problems have to be carried out. For example, calculating is certainly an activity common to human brains and computers but in the case of computers many relevant features of this activity are different from the meaningful traits singled out in the attempt to understand (this function of) the brain. We do not want to suggest that the results achieved in a given field are inessential to the work done in another field, but only that their interaction is not as strong as that between sciences which have been classified as different. Independent fields of study started to develop from this common frame as soon as they were able to shape an autonomous formalization. For example, after Kleene's theorem on the characterization of regular languages, the theory of automata was developed. This theory searched for its connections and established strong interactions with those fields that were closest to this profound mathematical characterization (that is, the theory of monoids and the theory of groups, combinatorics, etc.). It might be added that this new point of view allowed for emphasis to be laid on different visualizations of classical concepts and therefore a deeper understanding of the possible outcome of their development. Cybernetics was unable to provide the deep unification it was aiming at; a unification that had occurred other times in the history of science. Recall, for example, the theory of electromagnetism which unified optical, electrical and magnetic phenomena or Newton's theory of gravitation which unified celestial and terrestrial motion. This failure is so radical in so far as Cybernetics was meant not only to be a specific discipline (e.g. the science of control) but also a unifying paradigm. More precisely, it was seen as a new paradigm of scientific reason, as a unifying frame for other, already existing disciplines. Evidence for this claim comes from the fact that Wiener conceived Cybernetics not as a theory of control applicable (or applied) to animals and machines but as the study of communication and control both in animals and machines. The innovative idea was that insights coming from animals or machines could help one another in understanding problems, because they referred to different manifestations of the same phenomena. It is also worthwhile noting the widespread and substantial use made of general (and, at the time, innovative) concepts, such as complexity and information. In Cybernetics, one sees a considerable effort to extend the use of these notions to wider and wider domains, in particular, to new fields developing out of it. The success of the Cybernetics unifying program depends entirely upon the possibility of finding and developing a level of informational description. However, the only theory of information available at the time (and to some extent also today) was the theory of the transmission of information (to which Wiener himself made substantial contributions) which cannot be properly considered a theory of information. Thus, one understands why there were efforts to extend and find ever broader applications for what was available at the time. These efforts were of course of great value but uncritical extensions can produce dangerous consequences. Every new notion has a natural context of other related concepts and technical tools through which it is expressed and within which it has been conceived and developed. In any attempt to extend the use of any notion one has to take into account its context; the danger being that of creating conceptual monsters and theoretical constructions which give rise to doubtful interpretations. An example of this is provided by the use of the probabilistic theory of information transmission in fields where one can neither speak of probability nor of transmission (for instance, [1]).

3 About "Interdisciplinarity"

Another notion which has been discussed at length in Cybernetics is that of interdisciplinarity (for a few remarks, see, e.g., [10, 18]). One must acknowledge that Cybernetics was the first discipline to call real attention to this important notion, although it was unable to solve all the difficult problems connected to its handling. First of all, let us remember that interdisciplinarity played a considerably innovative and noteworthy anti-dogmatic role during the initial stage of Cybernetics. It was stressed that in the study of a new, difficult problem one has to make use of all available information - even if this forces recourse to different disciplines (and thus to different methodologies). Therefore the critical problem we want to raise about interdisciplinarity does not question this anti-dogmatic role, which was clearly positive. A more problematic issue regards the fact that its use was ambivalent: it is not clear whether interdisciplinarity was conceived only as an intelligent and new way of approaching problems or as a new fundamental tool to be permanently embodied in the new science. In the latter case we have a radically new approach from a methodological point of view - a new condition which requires articulation and inclusion in a new and complex program spelling out the pattern of the rise, evolution and interactions of the different disciplines. If one advocates interdisciplnarity without specifying this program - as actually occurred in Cybernetics - the evolution of the different disciplines involved is frozen. The notion of interdisciplinarity, if assumed uncritically, uses - as a matter of fact - the involved disciplines as fixed and unchanging, thus obstructing the evolution of new fields of investigation centered around problems which were initially examined by using interdisciplinary techniques. Only if the disciplines are fixed and static, does interdisciplinarity hold a permanent status: otherwise interdisciplinarity is part of a transient situation. In this latter sense we think of interdisciplinarity as playing a positive role in focusing new problems in scientific research. As the program develops and new results are obtained, (temporary) methodologies and new disciplines start to be shaped with specific tools and techniques - new disciplines which are determined by their most meaningful problems and by the conceptual and technical instruments which help in clarifying and solving them. This process can be usefully repeated as new problems arise and interdisciplinarity in this way is not interpreted as a defining feature of a field of study but only as a useful wide-ranging perspective for identifying and possibly solving new problems. If, on the other hand, interdisciplinarity is taken as a stable feature of a field of study, this implies that some problems can be studied only by means of a description involving several different disciplines. This fact includes the possibility of finding a language in which those problems might be independently investigated. Therefore a sound approach to interdisciplinarity could take into account only these two aspects: trivial (but useful) interpretation of interdisciplinarity (what we previously called the "wide-ranging perspective") and a more ambitious interpretation of it, seen as a search and study of regulating mechanisms for the interaction and development of various disciplines. The third view concerning interdisciplinarity in terms of a permanent category of research leads nowhere. Again, in the case of interdisciplinarity, we see the insurgence of a constant trait of Cybernetics, its capability of raising new and interesting problems coupled, at best, with its inability to understand its novelty and difficulty and at worst, with a reductive attitude which attempts to eliminate and ignore the actual difficulties. Let us remember that General System Theory (which, in my view, for a certain period was the sociological heir of Cybernetics) accepted most of the goals and aims of Cybernetics. In this new setting, however, the role played by the notion of interdisciplinarity was played by that of totality - a step forward in outlining a more general and ambitious plan, but a dangerous step backwards in terms of the effective construction of a rigorous scientific discipline.

4 *Apropos* of the original program

After a number of years, it became evident that the original program had not been successful. This does not imply a negative judgment on the whole enterprise or the acknowledgement of a failure. It happens quite often in scientific investigations that when you start looking for something, the results obtained frequently throw up something unexpected. In this case it is useful to reconsider the general goals of the program on the basis of the obtained results. The enterprise of Cybernetics has triggered general methodological considerations. First it is quite useless to "abstract at will". At some level of abstraction, only fairly unhelpful analogies remain, unless profound conceptual connections or deep mathematical results have emerged. Secondly, new disciplines of a very high (both conceptual and mathematical) standard have risen. Remember, e.g., the theory of formal languages, automata theory and the new impulse given to mathematical biology (Read the interesting papers by Aldo de Luca [11] and Luigi Ricciardi [12] also in this perspective). The unity was lost but a far deeper level of analysis was achieved for more restricted domains. These results have a positive value only if one takes them as new starting points and one accepts the conclusion to which they hint - that is, the primitive unifying program failed, at least in its original version. Of course, one may propose and develop new general programs. Alternatively, as most people did, one can follow more specific but more developed and (now) independent trends of research. Therefore, Cybernetics is in a quite peculiar situation. Its field of investigation is much broader than that of other traditional disciplines, while its instruments are by no means comparable to those of other sciences with a longer history, such as physics or mathematics. In this situation, two different tendencies emerge. On the one hand, is the tendency to make use of superficial analogies or to impose acritically mathematical formalizations to given problems, while on the other hand, is the tendency to concentrate solely on the problems of one of the specific theories. Therefore, the question which naturally arises is the following, is Cybernetics a single science? If we confine ourselves to the description of the situation, we face a dilemma. If Cybernetics is identified with one (or all) of its specific fields - each advancing in consonance with the nature of its particular problems - then criticisms concerning the scientific rigor of Cybernetics are neutralized. However, the outcome of this is the weakening of its unifying force and, above all, the relinquishment of the innovative theses which characterized Cybernetics from the start. As for unity, one can still maintain that work towards the clarification of the conceptual and the formal relations between the different branches might share an acceptable pattern of connections. What would definitely be lost, however, are the qualifying innovative points. If, on the contrary, one wants to preserve a strong unity together with the initial goals and ambitions, then the outcome is that of remaining at a very general level, without being able to support the ambitious program with a corresponding powerful quantitative and unifying apparatus of a mathematical and formal character. This latter position is, in our opinion, very dangerous. It might transform Cybernetics into a sort of technological myth, into an all-embracing philosophical monster which gives the (unreasonable) impression of being able to explain everything. An explanation of this view as well as of the initial success of Cybernetics (which cannot be found in specific technical results at its level of generality) can be supported by tracing a fundamental distinction between two levels which are clearly separated but which have constant interactions. One level is that of scientific results in a strict sense, while the other is the conceptual frame of the heuristic and regulative program. The program of Cybernetics was and still is clearly innovative. The partial results obtained during the first few years seemed to support the view that the program was likely to be entirely transformed into a scientific theory (which explains its initial success). The ensuing difficulties showed the impossibility of so doing and the difficulty of envisaging a new program of research in which one, being aware of the limitations, could work towards the realization of the initial goals along different paths. Part of the scientific community reacted by relaxing the requirements on scientific rigor, engendering confusion between the two levels - selling mere elaborations as scientific theory, even though sometimes quite sophisticated ones, of the program of research.

5 Provisional conclusions

What is or could be the current interest in the previous tentative reconstruction and analysis of such an old research program? In our opinion, the interest lies in the general questions and problems the analysis brings about, because the study of Cybernetics plays the role of a case study for several other disciplines which have grown and developed over the years. Its program of research was not formulated such a long time ago and was forced to face some central problems of scientific research in this century; sophisticated technology, complexity aspects, social pressure for (military) applications, etc. Moreover, the fact that it was unable to take off, ironically, gives us the opportunity to see better how a new science develops and what the problems it has to confront are. In particular, attention was drawn to some features of the general methodological attitude which pervaded this enterprise. For instance, the epistemological attitude in Cybernetics can be seen as a combination of some sort of naive mechanistic philosophy and of the belief that science develops in a way that one might call simplified Machism. This should also help in understanding why the primitive program was maintained in spite of results which - however interesting they might be in light of independent consideration - were not very meaningful or supportive with respect to the program of research. In our opinion, Cybernetics can be viewed as a concluded process which shares some very general goals and (part of) the epistemological attitude with many disciplines which are at the center of attention today. Hence, the present interest and the usefulness of looking at both the innovative and the weak points in the Cybernetics program of research. This thesis should be evaluated by analyzing in some detail the relations between Cybernetics and these other disciplines taking into account the intellectually stimulating points of view expressed in [8, 9, 10], which allow to review the thesis presented here in a more enlarged setting.

Acknowledgments First of all, I wish to remember Eduardo Caianiello who introduced me to the problems and mysteries of Cybernetics. My dialogues with Aldo de Luca have been so frequent and profound over so many decades that in some cases it is difficult for me to assign the origin of this or that point of view (which are part of my scientific image of the world) to him or to myself. My deep thanks to Luigi Maria Ricciardi for inviting me to participate in the “not to forget” session. He had the great idea of holding such an original session within his interesting Biocomp 2005. Thanks too, to the other participants in the special session who contributed in broadening and clarifying my views on these questions in a way which is not fully represented by what is written here. Last but not least, thanks to Guglielmo Tamburrini not only for many interesting discussions over the last few decades but also for having allowed me to steal, in an indecent way, the content of a joint paper.

References

[1] R. Arnheim (1969), *Entropy and Art*, University of California Press.

[2] J. Bečvàř (1984), Notes on Vagueness and Mathematics, in [13], 1-11.

[3] E.R. Caianiello, (1961), Outline of a theory of thought processes and thinking machines *J. Theor. Biol.*, **2**, 204-235.

[4] E.R. Caianiello, A. de Luca and L.M. Ricciardi, (1967), Reverberations and control of neural networks *Kybernetik*, **4**, 10-18.

[5] A. De Luca and L. M. Ricciardi (1972), *Introduzione alla Cibernetica*, Franco Angeli, Milano.

[6] A. De Luca and S. Termini (1972), A Definition of a non Probabilistic Entropy in the Setting of Fuzzy Sets Theory, *Information and Control*, **20**, 301-312. reprinted in *Readings in Fuzzy Sets for Intelligent Systems*, D. Dubois and H. Prade, and R. R. Yager (eds), Morgan Kaufmann, pp. 197-202 (1993).

[7] A. De Luca and S. Termini (1988), Entropy Measures in Fuzzy Set Theory, in M. G. Singh (ed), *Systems and Control Encyclopedia*, Pergamon Press, Oxford, 1467-1473.

[8] J. Mira Mira and A. E. Delgado Garcia (2005), On the Cybernetics roots of current artificial intelligence paradigms. *BIOCOMP 2005 Abstracts*, 15-16.

[9] R. Moreno-Diaz and A. Moreno-Diaz (2005), On the Legacy of W. S. McCulloch. *BIOCOMP 2005 Abstracts*, 17-18.

[10] A. De Luca (2005), Remarks on Cybernetics as an Interdisciplinarity Paradigm. *BIOCOMP 2005 Abstracts*, 22-23.

[11] A. De Luca (2006), Structure, Combinatorics, and Complexity of "Words", in [17], pp. 71-92.

[12] L. M. Ricciardi (2006), Modeling Single Neuron Activity in the Presence of Refractoriness: New Contributions to an Old Problem, in [17], pp. 133-145.

[13] H. J. Skala, S. Termini and E. Trillas (eds), (1984), *Aspects of Vagueness*, D. Reidel Publ. Co., Dordrecht.

[14] G. Tamburrini, S. Termini (1982), Do Cybernetics, System Science and Fuzzy Sets share some epistemological problems? I. An analysis of Cybernetics. *Proc. of the 26th Annual Meeting of the Society for General Systems Research*, Washington, D.C., January 5-9th 1982, pp. 460-464.

[15] S. Termini (1984), Aspects of Vagueness and Some Problems of their Formalization, in [13], 205-230.

[16] S. Termini (2002), Vagaries of Vagueness and Information, *Annals of Mathematics and Artificial Intelligence*, **35**, pp. 343-355.

[17] S. Termini (ed.) (2006), *Imagination and Rigour*, Springer, Milan.

[18] S. Termini (2006), Imagination and Rigour: their interaction along the way to measuring fuzziness and doing other strange things, in [17], pp. 157-176.

[19] J. van Heijenoort (1985),"Frege and Vagueness", in *Selected Essays*, Bibliopolis, Naples, **18**, 85-97.

[20] J. von Neumann (1951), The General and Logical Theory of Automata, in *Cerebral Mechanisms in Behaviour - The Hixon Symposium*, J. Wiley, New York (1951), (reprinted in [22], pp. 288-328).

[21] J. von Neumann (1956), Probabilistic Logics and the Synthesis of Reliable Organisms from Unreliable Components *Automata Studies, C. Shannon and J. MacCarthy (eds)*, Princeton University Press (1956) (reprinted in [22], pp. 329-378).

[22] J. von Neumann (1961), *Collected Works, vol V, Design of Computers, Theory of Automata and Numerical Analysis*, Pergamon Press, Oxford (1961).

[23] L. A. Zadeh (1965), Fuzzy Sets, *Information and Control*, **8**, 338-353.

Settimo Termini
Istituto di Cibernetica Eduardo Caianiello del C.N.R., Napoli
Dipartimento di Matematica e Applicazioni dellUniversità di Palermo
E-mail: `s.termini@cib.na.cnr.it, termini@math.unipa.it`