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Of Wiener And Bertalanffy Or The Dawn Of Complexity

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***Abstract*— This paper presents and compares "Cybernetics or, Communication and Control in the Animal and the Machine", from Norbert Wiener and "General System Theory", from Ludwig von Bertalanffy and shows how both relate to Complexity. As for presentation, the historical context of life and work of these authors is depicted, and the comparison is carried out through the analysis of chosen keys concepts where similarities and oppositions are highlighted. Since both areas developed a specific vocabulary but the original meaning might be different today, this article provides a specific definition and discussion section. The text concludes pointing out elements that are now present in the contemporary Complexity discourse.**

Keywords — Complexity, Cybernetics, General System Theory

I. Introduction

Ideas appear, interrelate, modify. Sometimes fade way or simply hibernate. So then, when we contemplate the intellectual tools at hand, it is important to ponder about their origins, history, and winding paths towards us.

Therefore, this article aims at helping to comprehend Complexity today, when regarding some of its first elements, namely, thinkers and projects that were born in the beginning of the 20th century, and that set themselves off to capture the essential mechanisms that govern life, human and animal behaviour, the relationships between human beings and machines, as well as how all these elements could be regarded as an integrated and interconnect whole. In essence, that is what "Cybernetics or, Control and Communication in the Animal and the Machine" [1] and "General System Theory" [2] are about (in this article, Wiener's book will be referred as Cybernetics with capital C and the research area, cybernetics; Bertalanffy's book will be referred as GST).

Knowing those author's motivations and their worldview including how they applied their theories may shed light on Complexity ideas, their possibilities and limitations and hopefully allow us to avoid past mistakes.

As a starting point for the present analysis, the Complexity Science Map [3] in Figure 1 displays at the beginning of its temporal scale (1940-1950) these two thinkers that somehow paved the way to the contemporary sense of the term Complexity, either in a philosophical inkling like Complex Thinking of Edgard Morin [4] or in pragmatic approaches as Complex (Adaptive) Systems or Complexity Engineering [5].

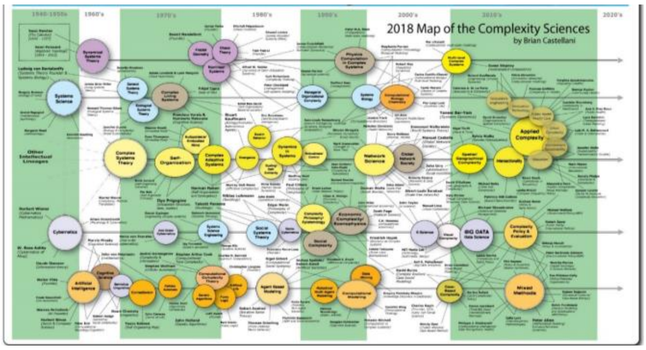

Figure 1 – Complexity Map [3]

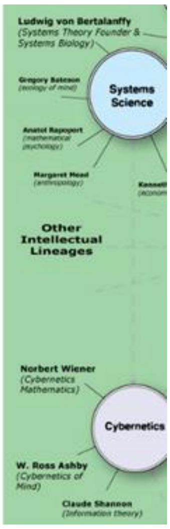

Figure 2 - Detail [3]

Let aside terminology, one thing is certain: Norbert Wiener and Ludwig von Bertalanffy developed ground-breaking ideas and concepts that dealt with the complex aspects of reality and also faced our inherently need to understand and try to control phenomena governed by laws and rules so elaborate, intricate and interrelated that humans (and even computers) are unable to perform.

This article will present and confront the works previously cited and show how they founded two scientific and academic study fields. The presentation part will describe a succinct historical context of each of the author's life and work. The ensuing part compares several important concepts and their view on each of them.
Both Cybernetics and GST have utilized or even developed a specific set of concepts which might presently have different meanings from their original inception when those books were written. Hence, this article has a section dedicated to explaining and discussing those terms.
We conclude with closing remarks about Complexity back then and today.

A. Context

We start giving a brief description of when lived and how worked Wiener and Bertalanffy.
Norbert Wiener (1896–1964) was an American mathematician who received his Harvard PhD in 1913 when he was 18 (!). He went on working at MIT and his main activities were related to mathematics where he developed analyses on Fourier series, Harmonic analysis, Ergodic Theory [1], among others. He has published over 250 texts [7].
Information theory was also, since its launch, in the realm of his interests, where he influenced even Shannon's main work:

> *Communication theory is heavily indebted to Wiener for much of its basic philosophy and theory. [8]*

In the beginning of the 1940s, Wiener as other scientists were engaged in the second world war efforts. From the analysis to understand machine functions and their parallel to human beings, he and his colleague Bigelow [2] contacted Dr. Arturo Rosenblueth, a Mexican physician researching in Harvard [1]. From this collaboration, the three researchers published an article [10] which forebears what was yet to come.
Cybernetics, published in 1948, was Wiener's research consolidation in the areas of animal and human physiology, control systems, computing systems, mathematical analysis of dynamical systems and, to some degree, social considerations on how technology would impact society. About the title, Wiener recounts:

> *We have decided to call the entire field of control and communication theory, whether in the machine or in the animal, by the name Cybernetics, which we form from the Greek $\chi\eta\beta\varepsilon\rho\nu\eta\tau\eta\xi$ or steersman. In choosing this term, we wish to recognize that the first significant paper on feedback mechanisms is an article on governors, which was published by Clerk Maxwell in 1868 and that governor is derived from a Latin corruption of $\chi\eta\beta\varepsilon\rho\nu\eta\tau\eta\xi$.. We also wish to refer to the fact that the steering engines of a ship are indeed one of the earliest and best-developed forms of feedback mechanisms.* [1]

The influence of this book was such that after little more than ten years later, when the second revised edition was published in 1961, the concepts of feedback and control systems were well established as an engineering and biology discipline in university courses.
The specific aspects and concepts of Cybernetics will be covered in the remaining of the article.
Karl Ludwig von Bertalanffy (1901–1972), was a philosopher with a PhD earned in 1926 from Vienna University but started his research in biology still in the 1920s, as shown his first publications [11]. As his work matures, the idea of "system" starts to get broader. He realizes the existence of relations between lower and higher levels of organizations and also, what he called "isomorphisms", that is, similarities from different kinds of systems: organic, mechanic, social and others [12]. These concepts and patterns are then condensed in the General System Theory, published in 1968 while he was already living in Canada. This work, according to the author himself ("the present work consists of studies written over a period of some thirty years." [2]) is a reunification of his papers, now structured as a single text. His ideas influenced several system researchers, especially those who focused on open systems.
Bertalanffy is actually not well known[3] and he alleges that not all researchers recognized his original ideas:

> *These remarks […] "organismic biology'' has been re-emphasized by leading American biologists (Dubos, 1964, 1967; Dobzhansky, 1966; Commoner, 1961) without, however, mentioning the writer's much earlier work, although this is duly recognized […] [2]*

As an explanation, it can be taken into account that a great part of his works was published in German and, that during the second world war period, Bertalanffy was a member of the nazi party [13].
Both, Wiener and Bertalanffy had a solid humanistic education and epistemological theories were familiar to them. In several passages of their books they mention ideas from Leibniz, Hume, Hobbes, Spengler, Kant, among others.
On the other hand, they avoided to elaborate metaphysical and philosophical explanations to phenomena. As can be read in Bertalanffy, for example:

> *[…] it is a conceptualization stemming from 17th century physics which, even though still prevailing in modern debates (Hook, 1961; Scher, 1962), is obsolete. In the modern view,*

[1] "it is the study of the long term average behavior of systems evolving in time." [6]
[2] mathematician and electrical engineer who developed the study of cybernetics and was the chief engineer of the IAS machine, which became the model for IBM's first all-electronic stored-program computer, the 701. [9]
[3] Google Scholar citations: Cybernetics: 16.998, e GST: 1387 – author's research in 18th may, 2020

> *science does not make metaphysical statements, whether of the materialistic, idealistic, or positivistic sense-data variety.* [2]

B. Methodological approach

The research of both authors – which today might be considered part of the great area of [General] System Theory or "General Systemology" as after [13] – analyzed problems like the mathematical modelling of living organisms phenomena and equilibrium mechanisms. But frequently with different forms.

Mostly through a practical manner, Wiener, understood that the control mechanism of action in living beings could be used as inspiration and model to build machines that, from the 1940s on, became more autonomous and were provided with logical (computational) control devices.

As a theoretical biologist, Bertalanffy considered organisms behaving as an open system, exchanging matter and energy with the environment while keeping themselves in a steady-state. This state is actually different from the entropic minimal energy level (which is explained further in this article) of closed systems. So, he concluded that such a system is capable of performing work as opposed to inorganic systems at minimum energy level state. To remain in such a state of equilibrium, living organisms have to constitute their own permanent self-organization.

C. The books

The first Cybernetics edition is divided into eight chapters to which two more were included in the second. According to Masani, citing Wiener himself, the book was written in the summer of 1947 following an invitation of a French editor, Freymann [15].

Each chapter handles a different topic, almost independent from each other. The several ideas and concepts converge in the end.

GST has ten chapters but, as it is the result of a rearrangement of several previous articles, there are repetitions and redundancies. The concepts are presented from a basic level of organization going up in a hierarchical structure until higher layers of complexity, both in living organisms as well as other contexts like social, organizational, and political.

In 1971 there was a second edition where two additional chapters were included but their content was already covered somewhat in the original edition.

D. Terminology

This section presents terms and concepts that can be considered keys to understanding further discussions in this article.

1) Open and closed systems

Systems are defined as "a set of interacting elements" [2]. A closed system is an idealized concept such that its elements interact only among themselves and not with the environment. This ideal scenario works well for limited systems (in space, time or both) like some machines or chemical processes.

On the other hand, an open system "is defined as a system in exchange of matter with its environment, presenting import and export, building-up and breaking-down of its material components." [2]

Wiener does not define systems. He employs the term when differentiating, for example, linear and non-linear systems and to deal with specifics, such as "nervous system"; additionally, in one of the new chapters of the second edition, he refers to "self-organizing systems".

2) Homeostasis

A living organism presents a set of internal processes like digestion, respiration, circulation, among many others. Each of these displays its own characteristics (e.g. pH, chemical elements concentration).

Homeostasis is than the capability of the organism to return to its natural equilibrium values, after a perturbation has occurred. Perturbations might be caused by internal changes like concentration rise or fall (e.g. blood pH) or external, like temperature or atmospheric pressure.

The concept was created by Walter Cannon:

> *The constant conditions which are maintained in the body might be termed* ***equilibria****. That word, however, has come to have fairly exact meaning as applied to relatively simple physico-chemical states, in closed systems, where known forces are balanced. The coordinated physiological processes which maintain most of the steady states in the organism are so complex and so peculiar to living beings - involving, as they may, the brain and nerves, the heart, lungs, kidneys and spleen, all working cooperatively - that I have suggested a special designation for these states, homeostasis. The word does not imply something set and immobile, a stagnation. It means a condition - a condition which may vary, but which is relatively constant. [16] (emphasis added)*

The ways that the organism employs to recover its equilibrium is exactly the goal the analyzed authors were seeking and, eventually, reproduce them in artificial systems.

3) Feedback

The concept of feedback consists in reintroducing part of the output (or result) of a process back into que input, so that we can control the behaviour of the output itself.

A typical example is the thermostat [1], which is an apparatus with a thermometer that controls an air-conditioning system to be activated or shut down, according to the desired temperature.

Although feedback mechanisms were long known and used, there was not a mathematical modelling such as Wiener's and their implementation in electromechanical systems was just starting.

4) Teleology

This fundamental philosophical concept allows for a long digression and discussion and it is key to grasp the kern of some intellectual disputes between cybernetics and general system theory.

It might be described as the “doctrine that considers the world as a system of relations between means and ends” [17]. In the same reference, the authors explain that through the years the term has had several meanings, especially in biology.

The discussion starts already with Plato and Aristotle and is not finished to the present day [18]; so this modest article will not try to solve the controversy but provide an overview on the issue.

An entity, be it a being, machine or society, is enabled with a teleological sense if it processes its activities with a specific goal, that is, a finality.

Teleology can be classified as extrinsic and intrinsic. In the former, finality is attributed externally to the entity (so the purpose of the fork is to be used to eat). In the latter, after Plato, purpose is “the nature of the being in itself”, as the nature of the horse is to reproduce in new horses [19], or that the feathers of the bird exist to keep it warm. In this last example, it becomes clearer the problem of cause and effect, in such a way that the effect (“feathers”) came into existence before the cause (“keep warm”).

Machines have external purposes. But for living organisms, this teleological logic does not have an answer.

Especially complex (here the first reference to Complexity in its philosophical sense) is the issue of purpose of (for) life, that is, which activities an individual or a society performs in order to fulfil any higher order purpose (which might even be unknown or not completely defined).

This debate recalls the discussion between mechanistic and vitalist explanation (discussed below) that also influenced both Wiener and Bertalanffy.

5) *Entropy*

It is the physical measurement that quantifies the organization (or disorganization) of a system [19]. Originally conceived in 1860 by German physicist Clausius, it aimed at quantifying the difference of the amount of heat able to perform work. The term Entropy was intended as a contraposition to the concept of Energy, where the Greek suffix “tropos” means transformation.

With the statistical mechanics from Boltzmann, Gibbs and Maxwell [1], Entropy’s meaning becomes the logarithm of the number of microstates that some gas particles could be at. The second law of thermodynamics utilizes Entropy to indicate the irreversibility of certain processes.

Later on, the concept widens towards the information theory field, following Shannon’s work and other initiatives that tried to reconcile thermodynamics and information theory [20].

6) *Vitalism*

The vitalist philosophy believes in a vital principle which bestow living beings its nature, which differs from inanimate objects.

> *Vitalists hold that living organisms are fundamentally different from non-living entities because they contain some non-physical element or are governed by different principles than are inanimate things. In its simplest form, vitalism holds that living entities contain some fluid, or a distinctive ‘spirit’. In more sophisticated forms, the vital spirit becomes a substance infusing bodies and giving life to them; or vitalism becomes the view that there is a distinctive organization among living things. (BECHTEL; RICHARDSON, 2007)*

Although the main scientific trends today completely reject the idea, it had important advocates in the past like Pasteur and Driesch [21].

7) *Mechanistic view*

The mechanistic explanation posits that natural phenomena are guided by a causal model that could be scientifically identified.

According to (AUDI, ca. 2006, p. 550–551), the mechanistic view varies:

> *[…] from the extreme position that all natural phenomena can be explained entirely in terms of masses in motion of the sort postulated in Newtonian mechanics, to little more than a commitment to naturalistic explanations[…]*

At the same time, this explanation is not entirely acceptable:

> *[…] Mechanism in its extreme form is clearly false because numerous physical phenomena of the most ordinary sort cannot be explained entirely in terms of masses in motion. Mechanics is only one small part of physics[…]*

And it also opposes to the vitalist explanation:

> *[…] to indicate that they included no reference to final causes or vital forces[…]*

Presently, from the mechanistic explanation can be stated that:

> *[…] In this weak sense, all present-day scientific explanations are mechanistic. […]*

It is important to realize, as can be read in Audi, how much of the contemporary thought still struggle with a mechanistic vision:

> *[…] we will be disinclined to explain human action entirely in terms of physicochemical processes. The justification for this disinclination tends to turn on what we mean when we describe people as behaving intentionally. Even so, we may simply be mistaken to ascribe more to human action than can be explained in terms of purely physicochemical processes. [19]*

This discussion is both relevant and fundamental when considering the analyzed authors. Not just to understand their prospective on world’s phenomena but also to conceive our own condition of being immersed in the aegis of the mechanistic view.

II. Comparative Analysis

Given the breadth of themes and ideas when comparing the works of Norbert Wiener and Ludwig Bertalanffy, it was necessary to narrow them down to a subset of the most important ones, considering their scientific approach and highlight similarities and discrepancies.

From the first definition of previous section, it is sensible to assume that both Wiener as well as Bertalanffy consider their research area as systems studies. Bertalanffy builds his entire corpus under this idea whereas Wiener does it in an indirect way because, in his writing, he names feedback as a "mechanism" and not often utilizes the word "system". But he does refer his research area as being constituted by systems:

> *We observed this pattern of contraction, paying attention to the physiological condition of the cat, the load on the muscle, the frequency of oscillation, the base level of the oscillation, and its amplitude. These we tried to analyze as we should analyze a mechanical or electrical system exhibiting the same pattern of hunting.* [1] *(emphasis added)*

The strongly mechanistic view of reality is another aspect that needs to be emphasized. Wiener believed in the human capacity of understanding and controlling nature and disdained those views that could be considered alternatives:

> *Vitalism has won […]; but as we have said, this victory is a complete defeat, for from every point of view which has the slightest relation to morality or religion, the new mechanics is fully as mechanistic as the old. […], and "materialism" has come to be but little more than a loose synonym for "mechanism." In fact, the whole mechanist-vitalist controversy has been relegated to the limbo of badly posed questions. (WIENER, 1971, p. 44)*

At the same time, Wiener had a reductionistic, even sometimes simplistic view of the biological reality of the organism.

Bertalanffy had a mechanistic view as well but emphasized that there were many aspects which were yet to be revealed and understood.

In their extensive three articles series [13], [23], [24], Pouvreau and Drack analyze Bertalanffy's oeuvre, comparing it to cybernetics. They do not restrict their analysis to Wiener's Cybernetics neither circumscribe the timeframe Cybernetics and GST were published. They also employed in their analysis the ever evolving cybernetics concept. Nevertheless, those articles are extremely profound and detailed thus deserve careful consideration.

In terms of similarities between Cybernetics and GST, they emphasize seven aspects, mentioned even by Bertalanffy himself, in a 1951 article:

1. Having an interdisciplinary character
2. Oppose a simple cause-effect model
3. Recognize that biology cannot isolate studied phenomena
4. Stress the importance of dynamical equilibrium
5. Overcome the antithesis structure-function
6. Re-orientation of the concepts of time and energy
7. Utilize the inductive method to develop laws and theories [24]

E. Feedback and open systems

The feedback concept is the core of Wienerian thought just as much as open systems are for Bertalanffy.

1) Feedback

In a certain way, the popularization and the mathematical modelling of the feedback was one of the main accomplishments of Cybernetics. The feedback mechanism, that was first formally described by Maxwell in 1868 [1], is presented in the book several times with various examples and considered as operating in a closed loop.

As already mentioned, the use of the feedback concept goes back to Wiener's work on anti-aircraft fire control, during the second world war. Back then he started to better understand the needs and difficulties in treating feedback for a real-time system and thought how to develop it mathematically, that is, what kind of information flow from the output to the input was required in order to direct future actions.

As previously discussed, this sort of considerations takes into account finality or teleology. But here there was no concern with the ontology of the finality, that is, how the aspiration to achieve an aim forms itself; in the case of mechanical and computational problems, the finality is external to the conceived system and it is attributed by its creator. Even when considering the human beings, Wiener has a more practical and objective manner:

> *The feedback of voluntary activity is of this nature. We do not will the motions of certain muscles, and indeed we generally do not know which muscles are to be moved to accomplish a given task; we will, say, to pick up a cigarette. Our motion is regulated by some measure of the amount by which it has not yet been accomplished. [1]*

In this excerpt he does not ponder how the will to pick up a cigarette arise. The context describes an action whose purpose is not questioned; only the decision to action is made explicit (see Teleology on section 4)).

After the end of the second world war, Wiener lets his considerations about mechanical problems mature, comparing them with those medical-philosophical developed together in the group led by Dr. Rosenblueth from 1933 on.

The convergence of conceptions that links living beings and machines culminates with the modelling of the systems feedback mechanisms, determining their behaviour and future states.

2) Open Systems

As a theorical biologist, Bertalanffy dedicated himself to model organisms as early as 1929 and by 1940 came to the concept of open system in equilibrium [22]. If for nothing else, organisms are open to exchange energy and matter that are, almost always, outside them.

When these considerations were to be applied to other kind of entities, trying to generalize the concept of system, it began to be evident that all systems can be classified as open up to a degree and that boundaries created to classify them as closed were expedients used by engineers and others to model processes more easily.
So, he went on defending and enhancing the open systems concept and tried to persuade other scientists in his quest.

3) Organismic view

The organismic theory from Kurt Goldstein was developed initially as a psychological scheme to understand the individual as a whole [25].
To explain the complex phenomenon of life satisfactorily, its self-organization and behaviours, Bertalanffy came up with the organismic point of view. According to it, life is maintained through different organization levels of the being, from the basic through the most elaborate and these different levels interact among themselves. The being behaves as an open system that receives and returns its material and energetic resources reaching homeostasis.
He considers the existence of four models (or classifications) for quantitative metabolism[4].

> *The models I chose are those of the organism as open system and steady state, of homeostasis, of allometry[5], and the so-called Bertalanffy model of growth. [2]*

Therefore, Bertalanffy considers feedback in organisms just one of the possible mechanisms that play a role in the living being, and in this context, the system aims at the homeostasis. He criticizes cybernetics for not acknowledging the many mechanisms of (self-) control:

> *cybernetic systems are a special case, however important, of systems showing self-regulation. [2]*

Historically, science in the 20th century considered that living beings could be treated as living machines, especially due to cartesian conceptions [1] [2]. Scientific (and/or philosophical) schools then were divided into mechanistic and vitalistic views. But Bertalanffy rejected emphatically such conception:

> *[...] according to the theory known as vitalism, explainable only by the action of soul-like factors—little hobgoblins as it were—hovering in the cell or the organism—which obviously was nothing less than a declaration of the bankruptcy of science. [2]*

Concerning finality or teleological aspects in the organism, Bertalanffy draws an extensive analysis [2]. Firstly, discuss causality. Rebuts the idea that life can be explained through pure mechanistic arguments. Further contends that causality and finality could be elucidated only through feedback. And concludes insisting that natural sciences can provide scientific explanations for directed behaviour.

4) Different points of view

Bertalanffy classifies types of finality:

1. Static, being the utilitarian (like hair to warmth and thorns to protect)
2. Dynamic. Subdivided in:
   i) Directed to a final state;
   ii) Direction based on the structure, like pH and thermoregulation;
   iii) Equifinality which has a vague definition but does not fit in both previous ones;
   iv) Purpose, in the Aristotelian sense, and inherent to human beings.

According to Bertalanffy, an open system can increase its order and also diminishes its entropy whereas a closed system based on feedback can only have lesser information, which is transformed into noise. The open system can actively increase its organization while a feedback system can only react through external information input.
And concludes:

> *In summary, the feedback model is preeminently applicable to "secondary" regulations, i.e., regulations based on structural arrangements in the wide sense of the word. Since, however, the structures of the organism are maintained in metabolism and exchange of components, "primary" regulations must evolve from the dynamics in an open system. Increasingly, the organism becomes "mechanized" in the course of development; hence later regulations particularly correspond to feedback mechanisms (homeostasis, goal-directed behavior, etc.). [2]*

Although Bertalanffy insists in the opposition of his theories and cybernetics to a certain extent, Wiener never regarded systems theory, either open or closed. The Cybernetics approach is more pragmatic and considers the specific system at hand.

> *However, this book is rather an introduction to the subject than a compendious treatise, and the theory of homeostatic processes involves rather too detailed a knowledge of general physiology to be in place here. [1]*

F. Entropy, Information, and Communication

From the previous sections about feedback and open systems, follows an analysis of the observables entropy. Likewise, there are considerations about information and communication. All these concepts which are intertwined now were, back then, heading still to unification.
It can be understood that Entropy was dealt sometimes as statistical mechanics according to Boltzmann and Gibbs and others as Informational, as in Shannon. The commutability of those concepts was being established:

[4] Set of integrated biochemical reactions in a living organism. [27]
[5] Allometry, also called biological scaling, in biology, the change in organisms in relation to proportional changes in body size. [14]

> *The notion of the amount of information attaches itself very naturally to a classical notion in statistical mechanics: that of entropy. Just as the amount of information in a system is a measure of its degree of organization, so the entropy of a system is a measure of its degree of disorganization; and the one is simply the negative of the other. [1]*

But their unification as interchangeable was yet not clear:

> *the cybernetic model—i.e., a system open to information but closed with respect to entropy transfer. This becomes apparent when the definition is applied to "self-organizing systems. [2]*

In this case, [24] consider that Bertalanffy's point of view was wrong.

We have now to analyze the concept of information and how it was employed in both theories.

Cybernetics dedicates two chapters to deal with the information concept. The third chapter, that deals with time series, information, and communication and the eighth, that deals with information, language and society. The term "information" is, at the same time, the essence of the feedback concept but also, a necessary input for systems organization (e.g. societies).

The time series chapter provides mathematical transformation of statistical data in time and its repeatability. In closing, he ponders briefly about quantum mechanics, then the forefront of information theory.

In the eighth chapter, on the other hand, presents some simplified and little scientific thoughts:

> *A group of non-social animals, temporarily assembled, contains very little group information, even though its members may possess much information as individuals. This is because very little that one member does is noticed by the others and is acted on by them in a way that goes further in the group. On the other hand, the human organism contains vastly more information, in all probability, than does any one of its cells. There is thus no necessary relation in either direction between the amount of racial or tribal or community information and the amount of information available to the individual. [1]*

Bertalanffy hardly utilizes the information concept. When he does, it is to discuss about cybernetics. He is not convinced of the role of information [theory] in the context of the living organism. Hence, he contends about the difficulties to reconcile informational concepts with the organisms' performance.

> *Information theory, in the sense of Shannon and Weaver (1949), is based on the concept of information, defined by an expression isomorphic to negative entropy of thermodynamics. Hence the expectation that information may be used as measure of organization (cf. p. 42; Quastler, 1955). While information theory gained importance in communication engineering, its applications to science have remained rather unconvincing (E.N. Gilbert, 1966). <u>The relationship between information and organization, information theory and thermodynamics, remains a major problem</u> (cf. pp. 151ff.). [2] (emphasis added)*

Here "remains a major problem" can be interpreted as being a great scientific challenge or his disagreement to relate the information concept with organisms.

Wiener understands communication as being a fundamental part of cybernetics, especially how communication takes place and, although the focus remains on electromechanical processes, there are references to communication through hormones, gestures and other organic modes.

> *[…] nerve fibers […] are often non-myelinated and are known to have a considerably slower rate of transmission[…] [1]*

On its part, Bertalanffy does nor employ the concept of communication but when he refers to feedback models of cybernetics. Whenever he mentions it, this is done in an informal way, meaning transmission of knowledge in human society.

G. Equation systems for organisms and machines

From a mathematical point of view, both authors have developed formal models for systems and mechanisms, although Wiener, given his education, has provided a more detailed and accurate description.

The Figure 3 below presents the feedback simplified model:

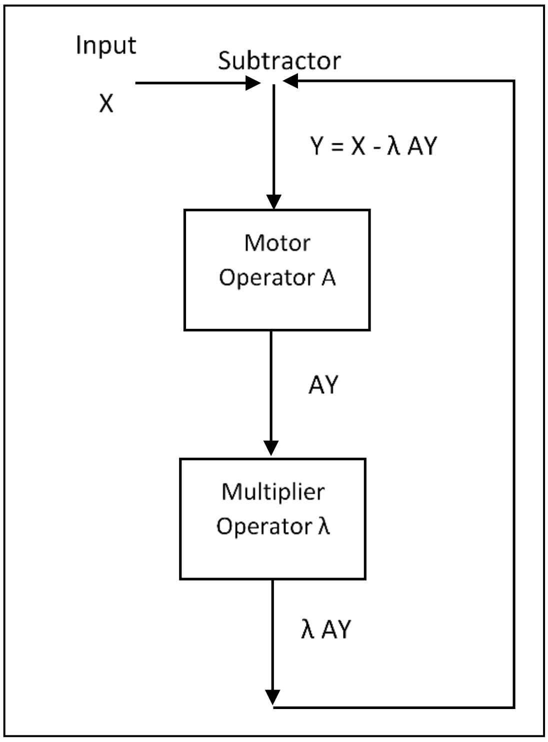

Figure 3 - Feedback scheme

$Y = X - \lambda AY$ (1)

After presenting equation (1) from the simplified model of the Figure 3, Wiener develops several analyses as to boundary conditions where it would be applicable, e.g., time aspects, solution space, adequate type of systems and oscillation problems.
By way of comparison, the organismic modelling of a system is shown in Figure 4. Although this picture is presented in the GST, the original source is [26].

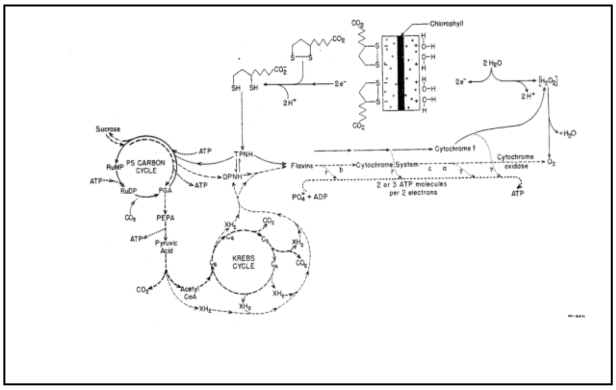

Figure 4 – Open system scheme showing photosynthetic reaction in algae [26]

To explain the behaviour in living beings, Bertalanffy employs equations to describe diffusion, metabolism, and catabolism[6] phenomena.
One of them is the differential equation for the steady state (2):

$$\frac{\partial Q_i}{\partial t} = T_i + P_i \ (2)$$

where Q_i represents the concentration of some element, T_i is this element transport speed and P_i, its production speed.
Next, Figure 5 presents a model for biological conditions [2] in which X represents material a_1 concentration, both inside and outside of the system. It can be processed in a reversible reaction (x_1 and x_2) or catabolised in x_3 and removed from the system.

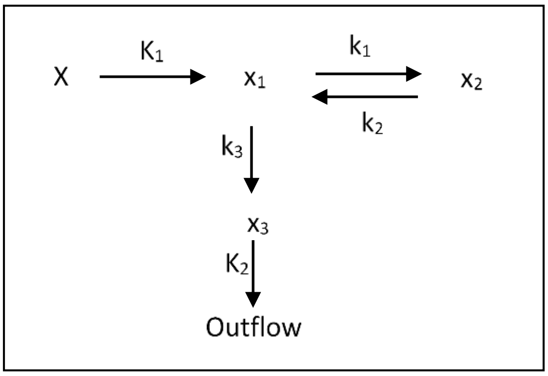

Figure 5 - Biological mechanism

When the organic model of Figure 5 is compared with Wiener's feedback in Figure 3, it is possible to visualize that a feedback chain is not always present in an organic system. Such absence does not imply however that in another higher hierarchical level, a feedback mechanism exists or not.
The differential equations for biological models and their solution space, as well as some indications on how to solve them, are presented in several parts of the GST but are beyond our scope in this article. Yet, it is important to emphasize that although not completely developed by Bertalanffy, the mathematical modelling of open systems is an integral part of an encompassing general systems theory.

H. Computers and nervous system

Computing did not exist as seen today when Wiener wrote Cybernetics. "Computers" were actual people who performed computations, that is, complex calculations.

> *These pieces of apparatus [...] are ail in essence quick-acting arithmetical devices, corresponding to the whole apparatus of computing machines and schedules, and the staff of computers, of the statistical laboratory. [1] (emphasis added)*

It is still foretelling how Wiener describes, in the introduction, the main characteristics computers (machines) should have, that they indeed have today.
On the other hand, he compares computers with brains, often in very oversimplifying manner. He likens the nervous system with a communication system and describes the behaviour of neurons equivalent to artificial devices. About brain cognition, he makes several different analogies since the brain controls basic metabolic functions, voluntary activities and, elaborate learning and understanding functions in animals and humans. In this sense Wiener employs those analogies according to the context but disregard that is the same organ performs all those activities.
Bertalanffy draws no parallel between nervous system and computers. Much on the contrary, in the GST he condemns emphatically many of his peers' behaviouristic approach ("[…] which sees no difference between human behavior and that of laboratory rats […]" [2]) which considered the brain programable. He also condemned the idea that human and machine behaviour were to be considered equivalent.

I. Psychology, Psychopathology and Psychiatry

Starting with the parallel from nervous system and brain with communication and control in machines, Wiener stablishes a causality notion. Hence, through the study of the psychopathological phenomena he identifies in the misbehaviours in human beings (basically related to motion), the parameters that ought to be controlled in machines for an adequate performance.
One of the neurological illnesses he studied was ataxia, a disturbance in the voluntary movements. Wiener believed in the need of a physiological cybernetics that would study the postural and voluntary feedback. [1]
Concerning psychological or psychiatric problems, he mentions several treatments of his time that varied

[6] Break down of complex molecules in a living organism, with energy release. [27]

from drugs to lobotomy and electrical shocks and that provoked harmful consequences. Thus, he advocates for psychology whose aim is to uncover and interpret hidden memories and helps with their acceptance hence making them less harmful. "All this is perfectly consistent with the point of view of this book" [1].

Bertalanffy considered that GST principles applied to psychological issues. This in agreement to system theory colleagues who subscribed that the concept of "wholes" would apply to any nature [2].

Dealing with what he called sciences of man (into which he included psychology, history, and social sciences), Bertalanffy considered the several strategies of psychology in that period. He affirms that it requires a holistic approach. In that sense, he thinks his model conflicts with the stimuli-response from other psychology schools, but he restates his believe that opposes to the stimuli-response technique as he considers the human being as an active, cultural, and creative being.

GST chapter nine deals specifically with psychology and psychiatric issues. Bertalanffy describes the main concepts of the system theory and how they apply to the areas connected to the psyche.

He conceives the organism as a dynamical order of parts and processes. And that it is active and not modulated by a stimulus-response mechanism. The concept of homeostasis was wrongly interpreted because it does not apply to dynamic regulation situations, spontaneous activities, growth processes, and creativity.

Other concepts discussed in that chapter like differentiation, centralization, regression, and symbolic activities do not directly derive from systems theory and will not be analyzed in the present context.

Bertalanffy concludes with a conceptual framework. He states that systems theory is psychophysically neutral and could be applied in psychology. The systems theory principles might lead to a behavioural and psychological unified theory. And that the discussion between free-will and determinism acquires new meaning, if will is not determined but determinable. Lastly, he states that responsibility should be considered in its moral and legal aspects, within the symbolic framework of society [2]. GST limits would vary from an objective level of theory applicability to a philosophical and epistemological level where he believes GST could discuss and systematize the above aspects.

III. Complexity

The relation between the concepts presented in this article are not self-evident because "the system theory and cybernetics intersect in an uncertain common zone" [4].

Problem description either in Cybernetics or in General Systems Theory time and time again employ the terms complex or complexity. This happens when describing a study object that presents difficulties to approach or problems hard to solve, with many variables, differential non-linear and non-trivial equations as well as unexpected and unpredictable behaviours. As a result, we believe that, when trying to tackle those challenges, the studied authors and their research fellows sowed the germs of Complexity. Morin, when explaining the foundations of the Complex Thinking in his texts often refers to Wiener and Cybernetics. There are also references to Bertalanffy, less frequently though.

> *The first "thought revolution" happens with the dawn of an organizational science. As I see it, the capital merit of Cybernetics founded by Norbert Wiener and the Systems Theory founded by Von Bertalanffy is that one and the other bring together the first tools to conceive organization. [28].*

Although Morin refers to the first use of the term Complexity [28] by Warren Weaver [29], there is enough evidence to show that both Wiener as well as Bertalanffy understood that there were problems and contexts to which it was not possible to address and even appreciate with the available scientific theories and methodologies.

> *In the human body, the motion of a hand or a finger involves a system with a large number of joints. The output is an additive vectorial combination of the outputs of all these joints. We have seen that, in general, a complex additive system like this cannot be stabilized by a single feedback. [1](emphasis added)*

Bertalanffy, whose book was published considerably after Wiener's, could include more consistently issues on Complexity. He cites Weaver's concept of Organized Complexity and some other aspects as the rise of complexity in organisms.

> *[…] namely systems organizing themselves by way of progressive differentiation, evolving from states of lower to states of higher complexity. [2]*

At the same time, his understanding of Complexity relates to the idea of systems with diminishing entropy, what would then justify the need for open systems.

> *Self-differentiating systems that evolve toward higher complexity (decreasing entropy) are, for thermodynamic reasons, possible only as open systems[...] [2]*

In GST, Complexity is used by Bertalanffy to describe a set of regulations or events in a system with a high number of variables, an interrelation difficult to be analyzed or a group of factors whose interaction can not be explicated or even recognized.

Therefore Wiener as well as Bertalanffy created their work and theories under a Complexity notion of the "complicated, difficult" which in turn recalls Morin's critiques of the use of the word Complexity in a reductionist way ("[…] we can not consider a complex system under the reductionist alternative[…]" [28]). Bertalanffy did understand that self-organization was a phenomenon whose complexity was far fetching from the current knowledge. But both, Wiener and Bertalanffy, had the expectation to be able to explain and control natural phenomena, even with a high number of variables and equations, through mathematical modelling that would describe all facets of nature.

To oppose this optimistic and naïve view of science's capacity to problem solving, they had a pessimistic feeling for humanity and its future.

> *As we have seen, there are those who hope that the good of a better understanding of man and society which is offered by this new field of work may anticipate and outweigh the incidental contribution we are making to the concentration of power (which is always concentrated, by its very conditions of existence, in the hands of the most unscrupulous). I write in 1947, and I am compelled to say that it is a very slight hope. [1]*

> *I believe the "decline of the west" is not a hypothesis or a prophesy - it is an accomplished fact. [...] We have to reckon with the stark reality of a mass civilization, technological, international, encompassing the earth and all of mankind, in which cultural values and creativity of old are replaced by novel devices. The present power struggles may, in their present explosive phase, lead to universal atomic devastation. If not, the differences between West and East probably will, one way or the other, become insignificant because the similarity of material culture in the long run will prove stronger than ideological differences. [2]*

The careers of these scientists went on for a couple of years after the publications of the works that were analysed here. Wiener passed way in 1964, after publishing several other books, articles and even autobiographies. Bertalanffy died in 1972, shortly after the publication of GST.

Both authors were prolific and the list of their complete oeuvres are respectively published by the Bertalanffy Centre for Systems Science Studies (BCSSS) [11] and in the exceptional and detailed book Norbert Wiener [7].

This article does certainly not encompass the analysis of all concepts and point of views of those authors in their main works; and not even consider their other publications. But, nevertheless, depicts to the contemporary reader the moments of the dawn of Complexity.

IV. Conclusion

The influence of Complexity in present day thinking is indisputable and publications are countless. Its extent encompasses from Morin in engineering [30], through physics, biology, mathematics, ecology, chemistry, and economy, besides its appearance in new areas such as architecture, consulting, product design, literary theory, and management [31].

But underlying this broad scope, an epistemological dispute, concerning the notions of "General Complexity" and "Restricted Complexity" ferments [32].

On the one side, philosophers, educators, and social scientists put forward an extensive and structured Complexity approach to analyse reality.

On the other, a more pragmatic, targeted modus operandi chosen by engineers and system analysts, doctors, and physicists among others, defends an applied Complexity, based on Complex Adaptive Systems, evolution models, and chaos theory, just to mention a few.

Looking some seventy years back, we could identify a pattern like what occurred between "cyberneticists" and "systemists" then.

Maybe, as explained in "The structure of scientific revolutions" [33], this is nothing but the struggle to establish the new paradigm. But it does provoke an unmistakable sense of déjà vu.

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