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CYBERNETICS 2.0

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The evolution of cybernetics (from N. Wiener to the present day) is briefly considered. A new development stage of cybernetics (the so-called cybernetics 2.0) is discussed as a science on general regularities of systems organization and control. The author substantiates the topicality of elaborating a new branch of cybernetics, i.e., Organization theory (O^3) which studies an organization as a property, process and system.

Keywords: cybernetics, organization, system, control.

1. Cybernetics of N. Wiener

This section is intended to consider in brief the history of cybernetics and describe “classical” cybernetics. Let us call it “*cybernetics 1.0*”.

CYBERNETICS (from the Greek κυβερνητική “governance,” κυβερνώ “to steer, navigate or govern,” κυβερνη “an administrative unit; an object of governance containing people”) is the science of general regularities of *control* and *information transmission* processes in different systems, whether *machines*, *animals* or *society*.

Cybernetics studies the concepts of control and communication in living organisms, machines and organizations including self-organization. It focuses on how a (digital, mechanical or biological) system processes information, responds to it and changes or being changed for better functioning (including control and communication).

Cybernetics is an *interdisciplinary science*. It originated “at the junction” of mathematics, logic, semiotics, physiology, biology and sociology. Among its inherent features, we mention analysis and revelation of general principles and approaches in scientific cognition. Control theory, communication theory, operations research and others represent most weighty theories within cybernetics 1.0.

In ancient Greece, the term “cybernetics” denoted the art of a municipal governor (e.g., in Plato’s *Laws*).

A. Ampere (1834) related cybernetics to political sciences: the book [2] defined cybernetics (“the science of civil government”) as a science of current policy and practical governance in a state or society.

B. Trentowsky (1843, see [61]) viewed cybernetics as “the art of how to govern a nation.”

In its *Tektology* (1925, see [10]), A. Bogdanov examined common organizational principles for all types of systems. In fact, he anticipated many results of N. Wiener and L. Bertalanffy, as the both were not familiar with Bogdanov’s works.

The modern (and classical!) interpretation of the term “cybernetics” as “the scientific study of control and communication in the animal and the machine” was pioneered by *Norbert Wiener* in 1948, see the monograph [69]. Two years later, Wiener also added society as the third object of cybernetics [73]. Among other classics, we mention *William Ashby* [4, 5] (1956) and *Stafford Beer* [8] (1959), who made their emphasis on the biological and “economic” aspects of cybernetics, respectively.

Therefore, cybernetics 1.0 (or simply **cybernetics**) can be defined as “THE SCIENCE OF CONTROL AND DATA PROCESSING IN ANIMALS, MACHINES AND SOCIETY.” An alternative is the definition of **Cybernetics** (with capital C, to distinguish it from cybernetics whenever confuse may occur) as “THE SCIENCE OF *GENERAL REGULARITIES* OF CONTROL AND DATA PROCESSING IN ANIMALS, MACHINES AND SOCIETY.” The second definition differs from its first counterpart in the words “general regularities,” which is crucial and will be repeatedly underlined and used below. In the former case, the matter concerns “the umbrella brand,” i.e., the “integrated” results of all sciences dealing with problems of control and data processing in animals, machines and society. The latter case covers partial “intersection” of these results (see Fig. 1 - figuratively speaking, the central rode of the “umbrella.”), i.e., usage of common results for all component sciences. Further-more, we will adhere to this approach over and over again for discrimination between the corresponding umbrella brand and the common results of all component sciences in the context of different categories such as interdisciplinarity, systems analysis, organization theory, etc.

Cybernetics today (disciplines included in cybernetics in the descending order of their "grades" of membership, see Fig. 1, with year of birth if available):

– *control theory* (1868–the papers [41, 67] published by J. Maxwell and I. Vyshnegradsky);

– *mathematical theory of communication and information* (1948–K. Shannon's works [55, 56]);

– *general systems theory, systems engineering and systems analysis* (1968–the book [9] and 1956–the book [26]);

– *optimization* (including linear and nonlinear programming; dynamic programming; optimal control; fuzzy optimization; discrete optimization, genetic algorithms, and so on);

– *operations research* (graph theory, game theory and statistical decisions, etc.);

– *artificial intelligence* (1956–The Dartmouth Summer Research Project on Artificial Intelligence);

– *data analysis* and *decision-making*;

– *robotics*

and others (purely mathematical and applied sciences and scientific directions, in an arbitrary order) including systems engineering, recognition, artificial neural networks and neural computers, ergatic systems, fuzzy systems (rough sets, grey systems, etc), mathematical logic, identification theory, algorithm theory, scheduling theory and queuing theory, mathematical linguistics, programming theory, synergetics and all that jazz.

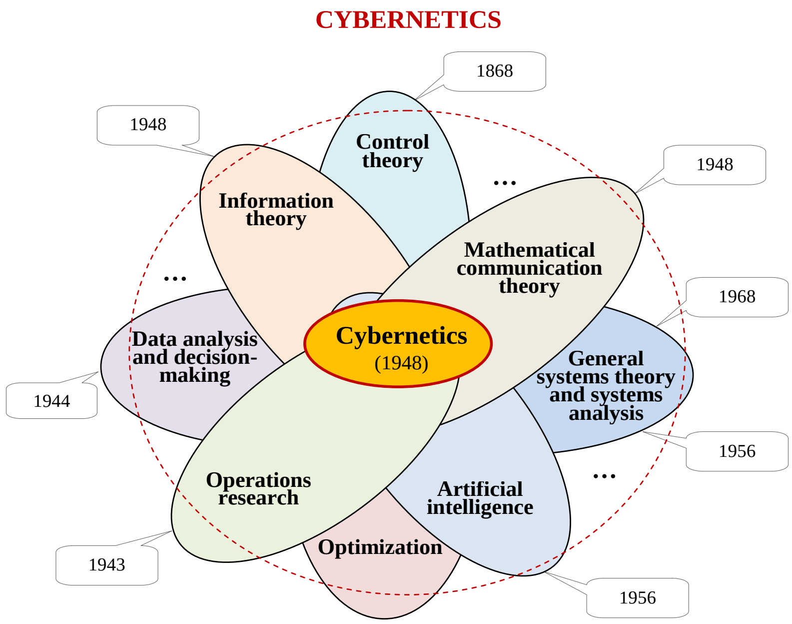

Fig. 1. The composition and structure of cybernetics

In its components, cybernetics intersects considerably with many other sciences, in the first place, with such metasciences as general systems theory and systems analysis and *informatics* (see below and [49]).

There exist a few classical monographs and textbooks on Cybernetics with its "own" results; here we refer to [1, 4, 7, 8, 9, 19, 20, 44, 70-73]. On the other hand, textbooks on cybernetics (mostly published in the former USSR) include many of the above-mentioned directions (*par excellence*, control in technical systems and informatics)–see [13, 22, 30, 32, 35].

The prefix "*cyber*" induces new terms on a regular basis, *viz*., cybersystem, cyberspace, cyberthreat, cybersecurity, etc. In a broader view of things, this prefix embraces all connected with automation, computers, virtual reality, Internet and so on.

Alongside with general cybernetics, there exist *special ("sectoral") types of cybernetics* [32]. A most natural approach (which follows from Wiener's extended definition) is to separate out technical cybernetics, biological cybernetics and socioeconomic cybernetics besides *theoretical cybernetics* (i.e., Cybernetics). It is possible to compile a more complete list of special types of cybernetics (see references in [49]): physical cybernetics (to be more precise, "*cybernetical physics*", see [17, 62]), *social cybernetics*, *educational cybernetics*, *quantum cybernetics* (quantum systems control, quantum computing), etc.

As standing apart, we mention a branch of biological cybernetics known as *cybernetic brain modeling* integrated with artificial intelligence, neural and cognitive sciences. A romantic idea to create a cybernetic (computer-aided) brain at least partially resembling a natural brain stimulated the founding fathers of cybernetics (see the works of W. Ashby [5], G. Walter [68], M. Arbib [3], F. George [18], K. Steinbuch [59] and others) and their followers (for a modern overview, we refer to [52]).

2. Cybernetics of Cybernetics and Other Types of Cybernetics

In addition to Wiener's classical cybernetics, the last 50+ years yielded other types of cybernetics declaring their connection with the former and endeavoring to develop it further.

No doubt, the most striking phenomenon was the appearance of *second-order cybernetics* (cybernetics of cybernetics, metacybernetics, new cybernetics; here "order" corresponds to "reflexion rank"). Cybernetics of cybernetic systems is associated with the names of M. Mead, G. Bateson and H. Foerster and puts its emphasis on the role of subject/observer performing control [6, 14, 15, 25, 42]. The central concept of second-order cybernetics is an *observer* as a subject refining the subject from the object (indeed, any system is a "model" generated from reality for a certain cognitive purpose and from some point of view/abstraction).

H. Foerster noted that "a brain is required to write a theory of a brain. From this follows that a theory of the brain, that has any aspirations for completeness, has to account for the writing of this theory. And even more fascinating, the writer of this theory has to account for her or himself. Translated into the domain of cybernetics; the cybernetician, by entering his own domain, has to account for his or her own activity. Cybernetics then becomes cybernetics of cybernetics, or second-order cybernetics." [15].

In contrast to Wiener's cybernetics, second-order cybernetics possesses *the conceptual-philosophical character* (for a mathematician or engineer, it is demonstrative that all publications on second-order cybernetics contain no formal models, algorithms, etc.). In fact, this type of cybernetics "transmits" the complementarity principle (with insufficient grounds) from physics to all other sciences, phenomena and processes. Moreover, a series of works postulated that any system must have positive feedback loops amplifying positive control actions (e.g., see [38]). But any expert in control theory knows the potential danger of such loops for system stability!

The "biological" stage in second-order cybernetics is associated with the names of H. Maturana and F. Varela [39, 40, 65] and their notion of *autopoiesis* (self-generation and self-development of systems). F. Varela underlined that "first-order cybernetics is the cybernetics of observed systems; second-order cybernetics is the cybernetics of observing systems." The latter focuses on feedback of a controlled system and an observer.

Therefore, the key terms of second-order cybernetics are recursiveness, self-regulation, reflexion, autopoeisis. For a good survey of this direction, we refer to [33, 51].

However, the historical picture has appeared much more colorful and diverse, not confining to the second order.

Some authors adopt the terms "*third-order cybernetics*" (social autopoeisis; second-order cybernetics considering autoreflexion) and "*fourth-order cybernetics*" (third-order cybernetics considering observer's system of values), but they are conceptual and still have no generally accepted meanings (e.g., see a discussion in [11, 27, 36, 37, 45, 63, 64]).

For instance, V. Lepsky wrote: "Third-order cybernetics can be formed basing on the thesis "from observing systems to self-developing systems." In this case, control is gradually transformed into a wide spectrum of support processes for system self-development, namely, social control, stimulation, maintenance, modeling, organization, "assembly/disassembly" of subjects and others." [34, p. 7793].

We point out other directions (see Table 1):

- *homeostatics* (Yu. Gorsky and his scientific school), a science studying contradictions control for the sake of maintaining the permanency of processes, functions, development trajectories, etc. [23];

– *neo-cybernetics* (B. Sokolov and R. Yusupov), an interdisciplinary science which elaborates a methodology of stating and solving analysis and synthesis problems of intelligent control processes and systems for complex arbitrary-nature objects [57, 58];

– *neo-cybernetics* (S. Krylov) [31];

- *control methodology* (D. Novikov) [48];

– *new cybernetics*, *post-cybernetics* (G. Tesler), a fundamental science about general laws and models of informational interaction and influence in processes and phenomena running in animate, inanimate and artificial nature [60]. Interestingly, K. Kolin had proposed almost a same definition to informatics 20 years before G. Tesler, see [28];

– *evergetics* (V. Vittikh), a value-oriented science about control processes in a society, which focuses on problem situations for a group of heterogeneous actors with different viewpoints, interests and value preferences [66]. In other words, evergetics can be defined as third-order cybernetics for interacting control subjects. According to Vittikh's fair remark, in everyday social life control processes will be realized by the "tandem" of common and professional control experts (theoreticians): the former face concrete problem situations in daily routine and acquire conventional knowledge (in the sense of H. Poincare) on the situation and define directions of its control, whereas the latter create necessary methods and means for their activity. Involvement of "common" people into social control processes is an important development trend of control science.

– *subject-oriented control in noosphere,* the so-called *Hi-Hume Cybernetics* (V. Kharitonov and A. Alekseev), a science mostly considering subjectness and subjectivity of control [24].

Table 1. Different types of cybernetics

Type	**Main authors**	**Period**
Cybernetics	N. Wiener, W. Ashby, S. Beer	the 1948-1950's
Second-order cybernetics	M. Mead, G. Bateson, H. Foerster	the 1960-1970's
Autopoiesis	H. Maturana, F. Varela	the 1970's
Homeostatics	Yu. Gorsky	the 1980's
Conceptual cybernetics of third and fourth orders	V. Kenny, R. Mancilla, S. Umpleby	the 1990-2010's
Neo-cybernetics	B. Sokolov, R. Yusupov	the 2000's
Neo-cybernetics	S. Krylov	the 2000's
Third-order cybernetics	V. Lepsky	the 2000's
New cybernetics, post-cybernetics	G. Tesler	the 2000's
Control methodology	D. Novikov	the 2000's
Evergetics	V. Vittikh	the 2010's
Subject-oriented control in noosphere (Hi-Hume Cybernetics)	V. Kharitonov, A. Alekseev	the 2010's

It is possible to introduce the notion of "*fifth-order cybernetics*" [49] as fourth-order cybernetics considering the mutual reflexion of control subjects [51] making coordinated decisions, etc. Note that all types of cybernetics in Table 1 are conceptual, i.e., absorbed by Cybernetics.

The observed variety of the approaches claiming (explicitly or implicitly) to be a new mainstream in classical cybernetics development seems natural, as reflecting the evolution of cybernetics. With the lapse of time, certain approaches will be further developed, others will stop growing. Of course, it is extremely desirable to obtain a general picture with integration, generalization and joint positioning of all existing approaches or most of them.

3. Cybernetics 2.0

The history of cybernetics and its state-of-the-art, as well as the development trends and prospects of several components of cybernetics (mainly, control theory – see also [16]) is briefly considered in [49]. What are the prospects of cybernetics? To answer this question, let us address the primary source– the initial definition of cybernetics as the science of CONTROL and COMMUNICATION.

Its interrelation with control seems more or less clear. At the first glance, this is also the case for communication: by the joint effort of scientists (including N. Wiener), the mathematical theory of communication and information appeared in the 1940's (quantitative models of information and communication channels capacity, coding theory, etc.).

But take a broader view of communication. Both in the paper [54] and in the original book [69], N. Wiener explicitly or implicitly mentioned interrelation or intercommunication or interaction–*reasonability* and *causality* (*cause-effect relations*). Really, in *feedback control systems*, control-effect is defined by its cause, i.e., the state of a controlled system (plant); conversely, control supplied to the input of a plant is induced by its cause, i.e., the state of a controller, and so on. No doubt, the channels and methods of communication are important but secondary whenever the matter concerns universal regularities for animals, machines and society.

A much broader view of communication implies interpreting communication as INTERCOMMUNICATION, e.g., between elements of a plant, between a controller and a plant, etc. including different types of impacts and interactions (material, informational and other ones). "Intercommunication" is a more general category than "communication."

In the general systems context, intercommunication corresponds to the category of ORGANIZATION (see its definition and discussion below). Therefore, a simple correction (replacing "communication" with "organization" in Wiener's definition of cybernetics) yields a more general and modern definition of cybernetics: "the science of systems organization and their control." We call it *cybernetics 2.0*.

Making such substitution, we get distanced from informatics. Consider the soundness and consequences of this distancing.

Cybernetics and informatics. Nowadays, cybernetics and informatics form independent interdisciplinary fundamental sciences [28]. According to a figurative expression of B. Sokolov and R. Yusupov [57], informatics and cybernetics are "Siamese twins." Yet, in nature Siamese twins represent pathology - for instance, the definition of informatics as the "union" of general laws of informatics and control would induce a megascience without concrete content, subsisting at conceptual level exclusively.

Cybernetics and informatics have a strong intersection (including the level of common scientific base–statistical information theory). Their accents much differ. The fundamental ideas of cybernetics are Wiener's "control and communication in the animal and the machine," whereas the fundamental ideas of informatics are formalization (theory) and computerization (practice). Accordingly, in the mathematical sense cybernetics bases on control theory and information theory, whereas informatics proceeds from theory of algorithms and formal systems. Note, that this distinction partly elucidates why some sciences often related to informatics or computer sciences have not been mentioned: theory of formal languages and grammars, "true" artificial intelligence (knowledge engineering, reasoning formalization, behavior planning, etc. instead of artificial neural networks as a modern empirical engineering science), automata theory, computational complexity theory, and so on.

The subject of modern informatics (or even the "umbrella brands" of *informational sciences*) covering information science, computer science and computational science [29] are informational processes.

Indeed, on the one hand, information processing arises everywhere (!), not only in control and/or organizing. On the other hand, informational processes and corresponding information and communication technology are integrated into control processes so that their discrimination seems almost impossible. A close cooperation of informatics and cybernetics at partial operational level will be continued and even extended in future.

Organization and Organization theory. According to the definition provided by Merriam-Webster dictionary, *an organization* is:

1. The condition or manner of being organized;

2. The act or process of organizing or of being organized;

3. An administrative and functional structure (as a business or a political party); also, the personnel of such a structure.

We'll use the notion "organization" mostly in its second and first meanings, i.e., as a process and a result of this process. The third meaning (an organizational system) as a class of controlled objects appears in theory of control in *organizational systems* [43, 50].

At descriptive (phenomenological) and explanatory levels [46], “system organization” reflects HOW and WHY EXACTLY SO, respectively, a system is organized (organization as a *property*). At normative level, “system organization” reflects how it MUST be organized (requirements to the *property* of organization) and how it SHOULD be organized (requirements to the *process* of organization).

Note that nowadays also exists “theory of organizations” (“organizational theory”) - a branch of management science, both in its subject (organizational systems) and methods used. Unfortunately, numerous textbooks (and just a few monographs!) give only descriptive generalizations on the property and process of organization in their Introductions, with most attention then switched to organizational systems, viz., management of organizations (for instance, see the classical textbook [12]).

A scientific branch responsible for the posed questions (*Organization theory*, or O^3 (organization as a property, process and system, by analogy to C^3 – Control, Computation, Communication [16, 49]) has almost not been developed to-date. Yet, this branch obviously has a close connection and partial intersection with general systems theory and systems analysis (mostly focused on descriptive level problems and a little bit dealing with normative level ones), as well as with methodology (as the general science of activity organization [46, 48]). Creating a full-fledged Organization theory is a topical problem of cybernetics!

Consider the correlation of the two basic categories in the definition of cybernetics 2.0 (“organization” and “control”).

Control is “an element, function of different organized systems (biological, social, technical ones) preserving their definite structure, maintaining activity mode, implementing a program, a goal of activity.” Control is “an impact on a controlled system, intended for ensuring its necessary behavior” [50].

Consequently, the categories of organization and control do intersect, but do not coincide. The former fits system design and the latter fits system functioning (a conditional analogy: organization corresponds to deism (the creator of a system does not interfere in its functioning), while control corresponds to teism (the opposite picture)); they are jointly realized during system implementation and adaptation, see Fig. 2. In other words, organization (strategic loop) “foregoes” control (tactical loop).

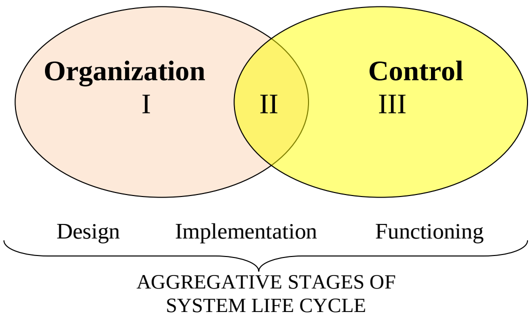

Fig. 2. Organization and control

The domains in Fig. 2 have the following content (as examples):

I. Design (construction) of systems (including their stuff, structure and functions)–organization but not control (despite that theory of control in organizational systems suggests stuff control and structure control).

II. Joint design of a system and a controlled object. Adaptation. Control mechanisms adjustment.

III. Functioning of controllers in technical systems–control but not organization.

On the one part, control process calls for organization (organization as a stage in Fayol’s management cycle and a function of organizational control, see [43]). On the other part, organization process (e.g., system life cycle) might and should be controlled.

Organization and control can have a “hierarchical” correlation. Generally speaking, the correlation of organization and control is far from trivial and requires further perception. For instance, in multiagent systems decentralized control (choosing the laws and rules of autonomous agents interaction) can be treated as organization. Another example is the Bible as a tool of organization [53] (a system of norms making common knowledge and implementing institutional control of a society).

Following the complication of systems created by mankind, the process and property of organization will attract more and more attention. Indeed, control of standard objects (e.g., controller design for technical and/or production systems) gradually becomes a handicraft rather than a science; modern challenges highlight standardization of activity organization technologies, creation of new activity technologies, etc. (*activity systems engineering*).

A fruitful combination of organization and control within cybernetics 2.0 would give a substantiated and efficient answer to the primary question of activity systems engineering: how should control systems for them be constructed? Actually, this is a “reflexive” question related to second-order and even higher-order cybernetics. Mankind has to learn to design and implement control systems for complex systems (high-technology manufacturing, product life cycle, organizations, regions, etc.), similarly to the existing achievements in technical systems engineering.

Cybernetics is important from general educational viewpoint, since it forms the integral modern scientific world outlook.

Cybernetics 2.0. We have defined cybernetics 2.0 as the science of (general regularities in) systems organization and their control.

A close connection between cybernetics and general systems theory and systems analysis [49], as well as the growing role of technologies leads to a worthy hypothesis. Cybernetics 2.0 includes *cybernetics* (Wiener’s cybernetics and higher-order cybernetics), Cybernetics, and *general systems theory* and *systems analysis* with results in the following forms:

– general laws, regularities and principles studied within metasciences–*Cybernetics* and *Systems analysis*;

– a set of results obtained by sciences-components (“umbrella brands”–*cybernetics* and *systems studies* uniting appropriate sciences);

– design principles of corresponding technologies.

Keywords for cybernetics 2.0 are *control*, *organization* and *system*.

Similarly to cybernetics in its common sense, cybernetics 2.0 has a *conceptual core* (Cybernetics 2.0 with capital C). At conceptual level, Cybernetics 2.0 is composed of control philosophy (including general laws, regularities and principles of control), control methodology, Organization theory (including general laws, regularities and principles of (a) complex systems functioning and (b) development and choice of general technologies), as illustrated by Fig. 3.

Basic sciences for cybernetics 2.0 are control theory, general systems theory and systems analysis, as well as systems engineering–see Fig. 3.

Complementary sciences for cybernetics 2.0 are informatics, optimization, operations research and artificial intelligence–see Fig. 3.

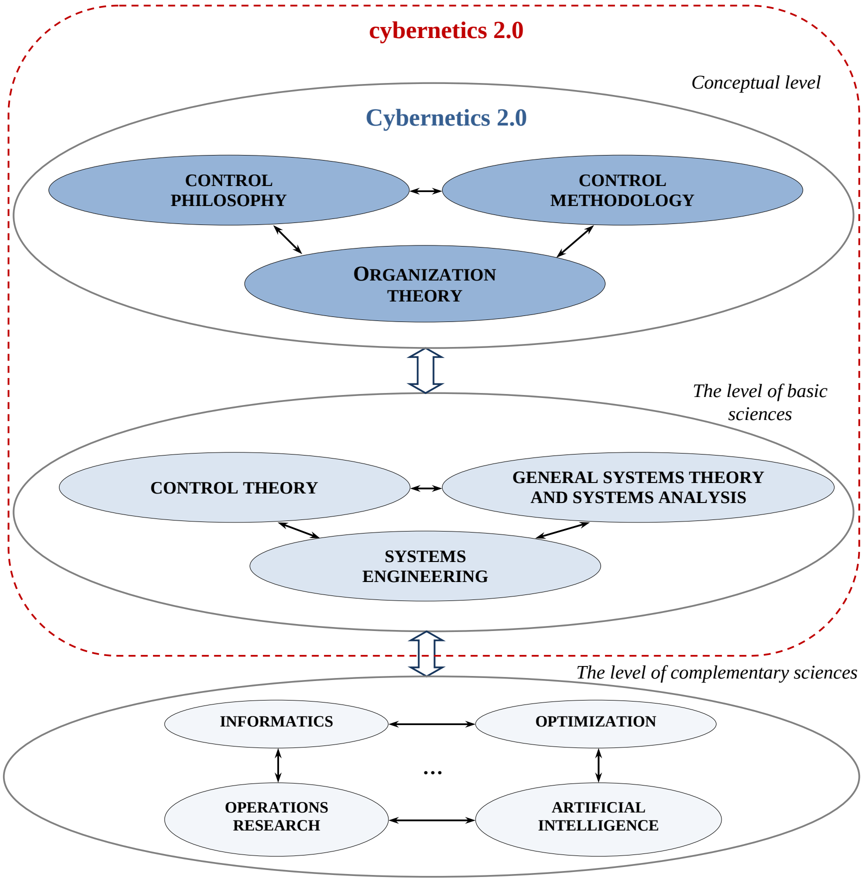

Fig. 3. The composition and structure of cybernetics 2.0

The *general architecture of cybernetics 2.0* (see Fig. 3) admits projection to different application domains and branches of subject-oriented sciences depending on a class of posed problems (technical, biological, social, etc.).

4. The prospects of cybernetics 2.0

Further development of cybernetics has several alternative scenarios as follows:

– *the negativistic scenario* (the prevailing opinion is that "cybernetics does not exist" and it gradually falls into oblivion);

– *the "umbrella" scenario* (owing to past endeavors, cybernetics is considered as a "mechanistic" (non-emergent) union, and its further development is forecasted using the aggregate of trends displayed by the basic and complementary sciences under the "umbrella brand" of cybernetics);

– *the "philosophical" scenario* (the framework of new results in cybernetics 2.0 includes conceptual considerations only–the development of conceptual level);

- *the subject-oriented* (sectoral) *scenario* (the basic results of cybernetics are obtained at the junction of sectoral applications);

– *the constructive-optimistic* (desired) scenario (the balanced development of the basic, complementary and "conceptual" sciences is the case, accompanied by the *convergence and interdisciplinary translation of their common results*, with subsequent generation of conceptual level generalizations (realization of Wiener's dream "*to understand the region as a whole*").

The development of cybernetics 2.0 in the conditions of intensified sciences differentiation provides the following:

- for scientists specialized in cybernetics proper and the representatives of adjacent sciences: the general picture of a wide subject domain (and a common language of its description), the positioning of their results and promotion in new theoretical and applied fields;

- for potential users of applied results (authorities, business structures): (1) confidence in the uniform positions of researchers; (2) more efficient solution of control problems for different objects based on new fundamental results and associated applied results.

Main challenges are control in social and living systems. Several classes of *control* problems seem topical, namely:

- network-centric systems (including military applications, networked and cloud production);
- informational control and cybersafety;
- life cycle control of complex organization-technical systems;
- activity systems engineering.

Among promising *application domains*, we mention living systems, social systems, microsystems, energetics and transport.

There exists a series of global *challenges* to cybernetics 2.0 (i.e., observed phenomena going beyond cybernetics 1.0), see [49]:

1) **the scientific Tower of Babel** (interdisciplinarity, differentiation of sciences; in the first place, in the context of cybernetics–sciences of control and adjacent sciences);

2) **centralization collapse** (decentralization and networkism, including systems of systems, distributed optimization, emergent intelligence, multi-agent systems, and so on);

3) **strategic behavior** (in all manifestations, including interests inconsistency, goal-setting, reflexion and so on);

4) **complexity damnation** (including all aspects of complexity and nonlinearity (Figuratively, in this sense cybernetics 2.0 has to include nonlinear automatic control theory studying nonlinear decentralized objects with nonlinear observers, etc.) of modern systems, as well as dimensionality damnation–big data and big control [47]).

Thus, the main *tasks of cybernetics 2.0* are developing the basic and complementary sciences, responding to the stated global challenges, as well as advancing in appropriate application domains.

And here are the main *Tasks of Cybernetics 2.0*:

1) ensuring the Interdisciplinarity of investigations (with respect to the basic and complementary sciences, as illustrated by Fig. 3);

2) revealing, systematizing and analyzing the general laws, regularities and principles of control for different-nature systems within control philosophy; this would require new and new generalizations;

3) elaborating and refining Organization theory (O^3).

We have described the phylogenesis of a new stage of cybernetics–cybernetics 2.0. Further development of cybernetics would call for considerable joint effort of mathematicians, philosophers, experts in control theory, systems engineering and many others involved.

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