Education as Cybernetic System

Ján Liguš
Department of Cybernetics and Artificial Intelligence
Technical University of Košice, Faculty Electrical Engineering and Informatics,
Letná 9/A 04120 Košice, Slovak Republic
jan.ligus@tuke.sk

Ján Sarnovský
Department of Cybernetics and Artificial Intelligence
Technical University of Košice, Faculty Electrical Engineering and Informatics,
Letná 9/A 04120 Košice, Slovak Republic
jan.sarnovsky@tuke.sk

Jana Ligušová
Department of Cybernetics and Artificial Intelligence
Technical University of Košice, Faculty Electrical Engineering and Informatics,
Letná 9/A 04120 Košice, Slovak Republic
jana.ligusova@tuke.sk

Iveta Zolotová
Department of Cybernetics and Artificial Intelligence
Technical University of Košice, Faculty Electrical Engineering and Informatics,
Letná 9/A 04120 Košice, Slovak Republic
iveta.zolotova@tuke.sk

Tomáš Gazda
Department of Cybernetics and Artificial Intelligence
Technical University of Košice, Faculty Electrical Engineering and Informatics,
Letná 9/A 04120 Košice, Slovak Republic
tomas.gazda@tuke.sk

Abstract—**Main idea of the paper is to look into education as to complex adaptive system from the cybernetics point of view. There is described the way how to define the system, with application to education and hierarchical structure of cybernetic system as well, in the paper. The variety and Ashby's law of requisite variety is explained and applied to education system. Every system has its surrounding, it is also the same in case of education system. Its surrounding is a practice. The advantages of mutual interconnection between the theory and the practice are shown and the risks of its absence are pointed.**

I. INTRODUCTION

Norbert Wiener defined the Cybernetics as the science of communication and control in the animal and the machine [1]. Today we also know the cybernetics includes control of very large-scale systems, control of live systems, control of social systems, etc.

Nowadays it is increasingly evident, that involvement of science leads to new view to the world. The universum reminds of great brain more then large machine – by these words glossed the situation in 1930 J. Jeans. During the twenties century was discovered the Einstein theory of relativity, quantum mechanics, Heisenberg's Uncertainty Principle, DNA decoding discovery, in the second half of the century by development of cybernetics and computer science arose artificial intelligence and continuously conceptions of complexity and chaos. All this expressly prove, that it is not possible to understand and explain the world by paradigms of 19th century.

The theory of relativity and quantum mechanics changed the seeing of the world. Nowadays we understand, or we try to understand, space and time totally different than before. There arose the image of the world as the multidimensional space-time. Quantum mechanics partly revealed the material base of the world, mostly in direction, that in principle it does not exist any final base, that matter is just the effect of energy. These concepts just rarely appear in the present schoolbooks of physics.

In [8] Education system is one of the most conservative social institutions. Present education structure and content is result of more than centenarian evolution. However, the 20th century brought radical advancement in area of science and gnoseology paradigms: till in the first half it was mostly the relativity theory and quantum mechanics, in the second half of the century it is mostly cybernetics together with development of computers, modern biology and sciences connected to the concept of complexity. Industrial age was based on the theories, those apperceived whole world as a machine. This image of the unified, mechanical and deterministic world formed not only science and technical development, but became dominant in the politics, economics in the organization activities and finally in the pedagogy and education.

In the twentieth century arose and arise new scientific paradigms. Let's mention just the relativity theory, quantum mechanics, Heisenberg's Uncertainty Principle, Goedel's theorems, cybernetics, computer science, modern genetics, chaos theory, memetics and the newest sciences about the complex adaptive systems, which are based on cybernetics and by synthesis with modern biology are trying to solve the problem of complexity. Nowadays, this concept is, or seems to be, the central point, center of the modern science.

II. Education as Cybernetic System with Dynamics

Firstly, let us look the way how to define the system. First of all we define the object of our interest selected from nature. Everything out of the object of the interest is surroundings (Fig.1). If the variables are defined on the object of interest, and relations among them, only then the system is defined. System consists of many elements (variables) and various kinds of multi-relations among them.

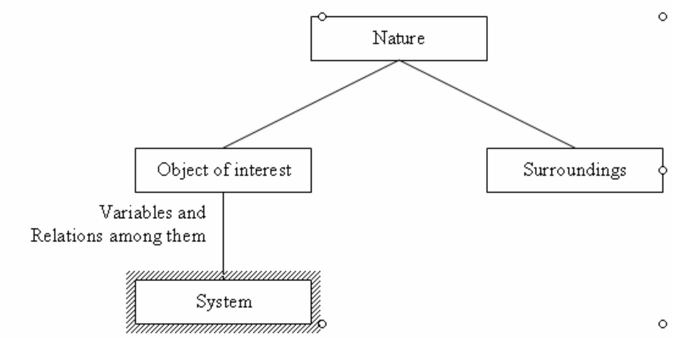

Figure 1: The way of the system definition from cybernetic point of view.

The set of all possible states that a system can be in defines its state space. An essential component of cybernetic modeling is a quantitative measure for the size of that state space, or the number of distinct states [6]. This measure is called *variety*. Variety represents the freedom the system has in choosing a particular state, and thus the uncertainty we have about which state the system occupies. Variety has always been a fundamental idea in Cybernetics and Systems Science. Variety is defined as a multiplicity of distinctions [1]. The existence of variety is necessary for all change, choice, and information. A reduction in the quantity of variety is the process of selection. If variety has thus been reduced, i.e. if actual variety is less than potential variety, then we say that there is constraint.

Frequently the quantity of variety and the change in the quantity of variety (positive increase or negative decrease) is critical to understand system evolution. Where variety is manifest in a process, then we sometimes want to say that there is uncertainty about the outcome of the process; when that uncertainty is relieved but the occurrence of one of the possibilities, then we gain information.

Concepts as chaos, complexity, complex adaptive systems are today the synonyms, which characterize today's dialectic complexity of the world as whole. They are simultaneously representing some trendiness, so many time their usage is not correct. There are such systems as brain, economics (enterprise, state, continent), colonies of ants or bees in our natural as well as in artificially created world. More complex are social-economy-cultural systems.

Therefore is suitable the very complex system to divide into hierarchical structure for exploration of its behaviour. According [2] the cybernetic system can be divided into three main levels: (1) organization, (2) coordination and (3) execution levels. Organizational level is level where strategies, planning and decisions arise and is mostly connected with intelligent functionality. Coordination level provides decomposition of the strategies, top planning into subgoals, subsystems and is mostly connected with autonomous functionality. The execution level is executing all subgoals and subtasks, influence the surroundings and is mostly connected with adaptive functionality.

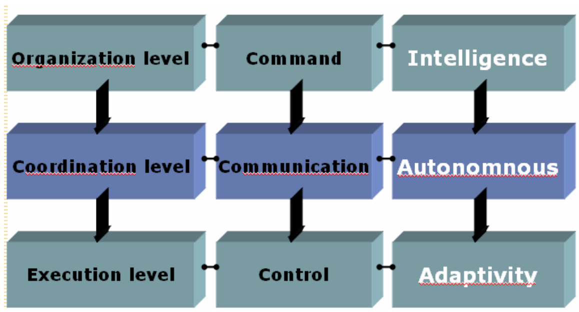

Figure 2: Hierarchical structure of cybernetic system and functionalities.

III. Education as Complex Adaptive Systems

We can characterize the Complex Adaptive Systems (CAS) through some of their essential characteristics [5]:

- Complex Adaptive Systems (CAS) are networks created from many subsystems-agents, which acts concurrently. If we consider e.g. economy systems, agents are companies. In case of political systems, the agents are a political parties, eventually dominant individuals of politic stage. In the international relations the agents are nations and states, or groups of states. In the complex energy systems they are energy units. It is typical, that agent acts in the continually variable environment, in interactions with other agents and this requires its continuous adaptation.
- CAS control is decentralized and autonomous. For example in a brain it does not exist any leading neuron. There are also many examples of the

autonomous systems without coordinator in the technical systems.
- CAS has usually multilevel structure with decentralization on every level (see Fig. 2).
- CAS continually changes its structure as a reaction to the environment. The principles of the adaptation are the same on every level.
- CAS are able, in simple or large scale cases, to realize prediction.

Kelly in [3] formulated very interesting features of the CAS in form of "nine rules of God":

1. Distribute the activities; new ideas, new organization forms, new structures are created as the result of the interaction of many parts.
2. Control in direction from down to up. Overall control should be result of parallel autonomous activity of subsystems (agents).
3. Grow new results. After the discovery of new result, skill or algorithm it is necessary to use, cultivate it.
4. Extend the system by chunks. It is necessary to start with simple system, which function and consecutively extend and improve it.
5. Maximally utilize the border areas. Sources of new ideas are often on the intersection of individual science areas.
6. Positive approach in case of mistakes. Mistakes are integral part of the creation process, as well as of our existence.
7. Not optimize for every price. CAS often function "sufficiently", as a result of many antagonistic goals.
8. Seek the disequilibrium. CAS works "on the edge of chaos".
9. Activate continual changes. Complex system works the best in state of the dynamic balance, in the continually variable conditions.

By conceiving the curricula for third millennium it is necessary to answer some essential questions which results from the formulations mentioned above:

1. What changes are necessary in the standard models of the present education plans and disciplines for preparation of students in bachelor, engineering and doctoral study in the global information society of the 21st century?
2. How to handle the fact, that research of many important problems requires to disrupt the balance of the present curricula of the subjects as well as to change the education contents and forms of the subjects?
3. How to create suitable ratio between the study subjects, which are in the list of study branches subjects and multidisciplinary study subjects?
4. If university aspirates to interdisciplinary studies, what is the range of the structural modifications of its faculties and departments?

Brief answers on questions given above can be e. g. artificial intelligence. Artificial intelligence is dominant paradigm of science in the third millenium, Artificial intelligence (AI) is wide science area, which consists of many related sciences as: neuroscience, psychology, cybernetics, linguistics, robotics, in essence it includes all areas which coheres with tendency to reproduce and simulate the methods and results of human intelligence and brain activities.

One of the ways how to reach the modern change in education is to understand the education process as CAS using the newest information technologies.

We should consider the education CAS as a set of mutually actuating communities, where each of them can be understood as the individual CAS. The subsystems are (from teacher point of view): teachers, administrative staff, students, financial sources and pedagogic tools (e.g. WWW) [7]. From the university teacher point of view there exists relatively weak interactions between individual disciplines as well as in direction to students. The CAS is more interesting from the student subsystem point of view. The student subsystem is joined with teachers, other students, real environment and future employee [4]. In doing so the interactions are bidirectional and relatively intensive. In regard the fact, that students are visiting different university workplaces, their view to the education and research can be very interesting.

Choice of education branch and individual study subjects should be highly individual. Some of students can choose the classical approach in direction "down-up", what means to create the specialization on the solid wide base. It is suitable to combine this approach with another in direction "up-down" and to choose appropriate knowledge base on the basis of specialization. The teachers should emphasize, that present complex systems are characterized by nonlinear, chaotic behavior and it is not possible to use for their control any global simple approaches of the "horse-sense" type. It is necessary to mention the use cases of the systems.

IV. EDUCATION AS SYSTEM AND ITS SURROUNDINGS

Before we will start to explain the education as system and its surroundings we have to mention one of the main principles of cybernetics, the Ashby's law of requisite variety.

Ashby's Law of requisite variety is:

1) the amount of appropriate selection that can be performed is limited by the amount of information available [1]. More information might be wasted but less information results in arbitrary decisions,
2) for appropriate regulation the variety in the regulator must be equal to or greater than the variety in the system being regulated [1]. Or, the greater the variety within a system, the greater its ability to reduce variety in its environment through regulation. Only variety (in the regulator) can destroy variety. It results from mentioned above, that

simple controller is not sufficient for control of the large-scale system. Another interpretation of this law is: the performance of the controller is adequate to the performance of the communication channel in the closed loop. The communication channel consists of two main parts, the direct link, from the controller to the controlled system and the feedback, from the controlled system to the controller. The performance of the communication channel is composed of both mentioned communication links. It is not possible to control the system without direct link. On the other side it is theoretically possible to control the system without feedback, but practically it is possible just in case of simple systems. It implies from the theory of discrete systems that quality of control is sufficient if the sample period of closed loop is six up to ten times faster then the fastest element of the controlled system. If we apply this scientific method to:

a. e. g. project management, it is necessary to have checkout project meetings 6-10 times within the project duration,
b. e. g. courses within the education process, it is necessary to check work of student in different forms (self evaluation tests, tests, essays, project results, seminars, programming results, coffee meetings etc.) 6-10 times per semester.

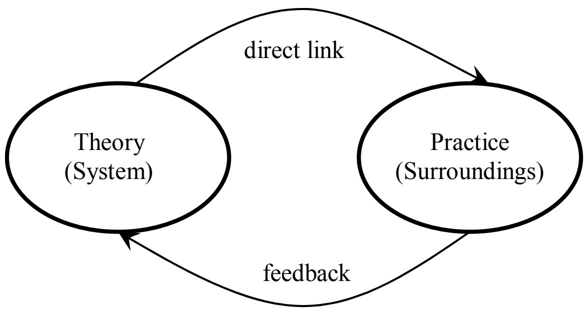

Figure 3: The diagram of the mutual interaction between the education system (theory) and its surroundings (practice).

One of the main surroundings of education system is practice, respectively industry, as shown on Fig. 3. There exists the mutual influence between the education (university, theory) on one side and practice (industry) on the other side. If the theory does not influence the practice in the direct link, the progress does not exist. In general, the practical engineers do not read the theoretical articles. They need proved results and not materials from fresh research findings. What they really need, they will find in the application journals, as in commercial publications. On the other side, if the theory does not influence the practice in the feedback, the progress does not exist as well. If the feedback from practice to theory will weak-up or will be interrupted, then theory is sterile, preserved and not observable. In this case the theory is not controllable, the theory is developing according its own logics and intellectual interests. If the practice do not provide suggestion to theory, the theory becomes closed.

The start point is to find the relevant range of all these mutually influencing factors. Why is not the behavior of the real industrial complex systems researched theoretically? The gap between the theory and practice in automation is bigger, than it seems to be. For example, there are not up to now completely explained very simple problems, e.g. why the classical PID controllers are effective without the identification and optimization of control processes. The answer is intuitively clear, but exact explanation requires some intellectual effort. One of the approaches is the approximation of the mentioned system by linear model with constant parameters in the certain area of changes of variable parameters and by using the principle of requisite variety, respectively the principle of system and controller adequacy we can easily proof, that PID controller handles variety (is adequate to controlled system) of outputs (states) of the controlled object.

The recommendations of interconnection between the theory and practice are as follows:

- Strengthen interaction, knowledge exchange and transfer between the theory and practice, in order to increase "return-on-investment".
- Increase the activity level of Europe's R&D as CAS, provide strategic and operational guidance for upgrading of education & training systems and curricula in EU
- Academia and industry will explore together new design possibilities.
- Academia and industry will meet all experts of the from technology to application
- Establish global coordination and cooperation

There are drawn the advantages of connections between theory (universities) and practice (practice) in all combinations of mutual influences (university to industry, industry to university, industry to industry, university to university) as shown in Table 1.

to \ from	Universities	Industry
Universities	• scientific collaboration • exchange of people	• technological know how • funds (mostly US?) • source of problems (inspiration)
Industry	• young people • connection to world's knowledge • innovative ideas • culture as product	• the value chain (ecosystem) • the economic basis

Table 1: Advantages of connections between universities and industry.

V. Conclusion

We can conclude that from the cybernetic point of view, the education can be defined as a system. We considered the education CAS as a set of mutually actuating communities, where each of them can be understood as the individual CAS. This CAS is created from many subsystems-agents, which acts concurrently. The cybernetic principle of requisite variety can be very effectively applied to the education system with all its three interpretations. We applied the bridge between the theory and the practice by system approach that the theory is a system and practice is surrounding of the system. We brought specific view regarding the interconnection between the theory and the practice as well the advantages of connections between universities and industry.

It is necessary to build and keep up the bridge between the theory and the practice. What we need is opened theory and opened practice. This process will never end, every generation must to make new effort in this direction. But the first step has to be made by theoreticians.

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