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Twenty Years of the Czechoslovak Academy of Sciences and the Development of Cybernetics

The twenty years of existence of the Czechoslovak Academy of Sciences, which is the top scientific organization consisting of a system of scientific institutes involved in basic research in all significant fields, has become the era of real prosperity of our science witnessing the important support which is granted to the development of science by the socialist society.

The Czechoslovak Academy of Sciences was founded in 1952 after a period of careful preparations. The Academy originated as a result of the reconstruction of the former national scientific institutions known as the Royal Bohemian Society of Sciences (established 1784) and the Czech Academy of Sciences and Arts, which together with the Charles University represented our scientific activity and tradition. The new system of institutes, scientific boards, commitees and societies established since 1952 thus not only continued the progress of our science but also focused of the most important areas and modern trends in science. The fact that the Czechoslovak Academy of Sciences was headed by Zdeněk Nejedlý, our top expert in progressive and scientific tradition as well as a pioneer of the socialist orientation in our science, symbolizes the unity of historical continuity and modern orientation.

When the Czechoslovak Academy of Sciences came into existence, it consisted of seven institutes with about a thousand personnel total. During the first five years the basic system of research centers was established, consisting of institutes or their preparatory form (laboratories, independent departments). Systematic support of our society has resulted in creating a research system involing all fundamental theoretical fields of modern science. Thus Czechoslovakia became one of the main centres of the research activities. This can be demonstrated not only by the fact that the number of scientific workers has increased more than ten times, but also, and primerily, that in the last decade the social-economic and technological impact of science increased tremendously. This increase is the merit of the Czechoslovak Academy of Sciences together with our universities and branch research institutes of

applied science. The social role of the research system will be further developed under the conditions of the international scientific integration and the division of labour in science.

Since the first year of the Academy the areas related to theoretical cybernetics have been given much attention. Cybernetics, being a complex science involving both theoretical and applied aspects, has attracted interests of several research centers of the Academy and our universities. In the fifties, cybernetics was a newly-born field without an appropriate institutional basis and therefore the interest in cybernetics was rather spontaneous. Cybernetic problems were discussed in small groups of specialists in mathematics, medical and biological sciences, engineering, etc. In the field of medical and biological sciences it was Professor Charvát who promoted cybernetics in the late forties. On behalf of matematicians, Dr. Špaček, together with his collaborators, was the first to recognize the significance of cybernetics and to elaborate its principles. Dr. Špaček was our most active pioneer of cybernetics, giving lectures, writing papers and initiating discussions. His premature death in the full scientific activity was a big blow to our science.

The necessity of institutional basis for principal theoretical areas related to cybernetics in the last fifties led to the foundation of the Institute of Information Theory and Automation headed by Academician J. Kožešník. This institute became the most important centre of theoretical activity in this field.

Cybernetics is a interdisciplinary field requiring a fruitful interaction and cooperation of experts working in various topics of communication and control. Therefore discussions, lectures, seminars stimulating the interdisciplinary interaction were so important. They resulted in the progress of theoretical cybernetics as well as its applications in biology, medicine, logic, semantics and linguistics, psychology and pedagogy, and in such problems as diagnostics, the quality and reliability control, data processing, etc. To coordinate this activity, the Cybernetics Committee of the Academy was established in the late fifties. The first chairman of the Committee was Prof. Zich.

In the early sixties this interdisciplinary cooperation expanded to such an extent that further steps has to be taken. The **Czechoslovak Association for Cybernetics** was established under the auspices of the Czechoslovak Academy of Sciences. The Association brought together specialists of various spheres of cybernetics. Its first chairman was Dr. Perez.

It was important for the progress of cybernetics to have publication possibilities. Even though significant works, e.g. conference proceedings, were appearing in the fifties and early sixties, establishing of the journal **Kybernetika** was an important event. It has been appearing bimonthly since 1965. It was the journal of the Cybernetic Committee and later of the Czechoslovak Association for Cybernetics and is published by the Institute of Information Theory and Automation. This journal shows also the fruitful international collaboration in various fields of cybernetics, especially with USSR and other socialist countries.

The Institute of Information Theory and Automation together with some other institutes of the Academy of Sciences participate in the basic research of cybernetics. A brief review of this activity will be given. Most of the results have already been reported in various journals including the journal Kybernetika.

The **Institute of Information Theory and Automation** originated in 1959 by joining the group of Dr. Špaček and the former Laboratory for Automation. The new Institute continued the activity of both groups. Dr. Špaček's group was engaged in the probability theory, mathematical statistics and their applications. Dr. Špaček well recognized the new trends in the probability theory. He formed a strong group of yound scientists, one of the world's leading groups in this area. This is demonstrated by the international Prague conferences held since 1956, where the topics of information theory, statistical decisions and random processes have been discussed. The Sixth Prague conference was held in 1971. They were all very successful and Prague has become the meeting place of the experts in probability theory throughout the world.

Beside the theoretical research, an experimental activity was established that was designing special devices for generating random processes. A large theoretical group cooperating with a well-equipped experimental group was a novelty at that time which was followed by other institutes.

The probabilistic methods studied in the Institute involve mostly the information theory, in particular the general concepts regarding the transmission of signals and messages with the presence of noise. The logical fundamentals of information theory based on the relative frequency of errors were developed. For the first time the transmission of general objects (patterns, curves, etc.) rather than letters was considered. The best coding of transmitted information was investigated which eliminates noise as much as possible while keeping the cost within reasonable limits. In all work the relation between information theory and statistical decisions has been emphasized. It was revealed that the mathematical concepts considered in the information theory also characterize the respective problem of coding and decoding transmitted information. Hence the scheme of data reduction was introduced which is still given much attention at present. Results obtained in the studies of data reduction problems were applied in some fields, namely in medical diagnostics and pattern recognition. In the field of statistical decision some new approaches were elaborated, e.g., the principles of the experience theory, new results in the field of adaptive and learning systems, etc.

All the above problems are closely related to the control of random processes. The results obtained in the Institute started from the theory of Markov processes. The Markov processes themselves have been studied by Academician Kožešník, to mention the applications to the continuous microorganisms, cultivation, to the planned control in economical problems, etc. As far as the control of Markov processes is concerned, research is being done in the queueing theory, the optimal renewal theory, fault detection, etc.

The results on statistical decisions and other related fields are closely connected

with some industrial and technological applications, in particular in the sphere of statistical quality and reliability control. These applications stimulated some new theoretical activities as e.g. determining the sampling plans of the supplier given the sampling plan of the customer, sampling plans for several quality properties, comparing the optimal statistical controls, element redundancy to increase the system reliability, technical diagnostics, etc.

In addition to the theoretical results several unique devices have been produced. The first was the special computer SARO for modeling the sampling plans in statistical quality control. A part of this device, the random process generator, was subsequently modified into a series of instruments GENAP. These instruments are able to generate various types of random processes. They can be used either independently or in conjuction with the special analogue computer ADAPP (developed in the Institute) for solving problems in engineering, biology, economy, etc. Random process generators of GENAP series are used in several institutes in Czechoslovakia and abroad.

In the field of control theory, the Institute continued the work of the former Laboratory for Automation. The first theoretical works involved the general problems of control of linear systems, namely the stability and quality analysis of control processes, the computations of transients, the control of special plants (power boilers), etc. To solve these problems, the differential analyzer DIANA, the first computer of its type in Czechoslovakia, was designed.

Activity of the Institute in this field was well programmed. As a consequence the works of the Institute are assuming high reputation. The Institute was one of the first to investigate the control theory of industrial processes using a digital computer. A large number of publications have appeared on this particular topic.

Another area, in which significant results have been obtained, is the mathematical description of industrial processes which is necessary for control. At first, the method of mathematical/physical analysis was employed and original results have been obtained, mostly for thermal, power and chemical systems.

The present activity in this area involves the system identification, i.e., obtaining a mathematical model for industrial systems by processing experimental data measured on a real system. Several methods proposed in the Institute have attracted experts from abroad and the Institute was entrusted by the Interntaional Federation of Automatic Control (IFAC) to organize international symposia on this topic. They were held in Prague in 1967 and 1970.

Another large area of research – the adaptive and learning systems – can be divided in two principal fields. The first concerns on the continuous controllers that automatically adapt to the changes in the system being controlled and in the noise contaminating the control process. The task is to develop simple and reliable adaptive controllers, well suited to mass production, which would replace the conventional fixed-set controllers. The second field envolves the elaborations of numerical algorithms to find the optimal control strategy. The task is to program a computer so that

it may automatically control a complicated technological process with large number of controlled variables, and may adapt to operating conditions. The principal applications are expected in the control of mass production.

The results obtained in the Institute are widely applied. To facilitate the applications, the six-channel universal statistical analyzer MUSA 6, the sixteen-channel recorder ZAZA 16, and the incremental magnetic-type recorder KMZ 1000 were developed. These are designed for fast data processing in automatic control, and can be applied in other branches, too.

Besides the Institute of Information Theory and Automation, the main contribution to the development of theoretical cybernetics is due to the **Mathematical Institute.** A relatively small yet very active group was elaborating the mathematical aspects of cybernetics, particularly within the fields of mathematical logic, the automata theory, the theory of languages, programming languages, and algorithms.

As to the general and logical problems of cybernetics, the GUHA method for automatic generation of hypotheses from experimental data should be mentioned. Also an original theory of automatic processing of observed data was established. A number of results originated in the area of automata theory and related problems. It was proven that the uniqueness problem for higher-order coding systems is algorithmically undecidable. The graphs embeddable into Booleans cubes were characterized, and properties of the completness number of graphs were studied. The concept of a multiple automaton was introduced and new results were attained in the theory of asynchronous automata. The properties of mappings realized by various types of Turing machines were investigated.

A remarkable progress was achieved in the theory of languages, namely in Chomsky's classification on languages and grammars, and in the area of transformational and context-free grammars. A proof of equivalence of various types of terminal conditions in generative systems was given and it was proved that one-sided context grammars have greater generative power than context-free grammars. Further, grammars with ordered rules were defined and their generative power investigated. Also the concept of a regular approximation of a language was introduced together with several modifications of the notion of a conditional context-free grammar. Finally, a theory of linguistic approximations was developed with connection to the transformational grammars.

Programming languages and the automata theory are very useful in computational applications. The research in this direction was concentrated mostly upon the semantics of programming languages, and characteristic features of simulation languages were analyzed. New concepts in the field of programming languages analysis, namely the concept of well-translatable grammars, were defined. The complexity measures of special programming schemata were studied and algorithms for their minimization were given. In cooperation with external experts, the structure and semantics of the programming language ALGOL 68 was analyzed. As to the theory of algorithms, the algorithmic complexity problems were investigated. Several notable results

were achieved concerning various measures of algorithmic complexity of discrete programming problems. Estimates of the approximate program complexity of recursively enumerable sets were obtained and the notion of final program complexity of partially recursive functions was introduced.

Numerous conctacts with other areas should also be mentioned, as well as a regular seminar devoted to the automata and language theory, which has been organized by the Institute since 1959.

Whereas the Institute of Information Theory and Automation and the Mathematical Institute constitute the basis for the theoretical research of cybernetics, several other institutes have been applying the cybernetic methods. Several specialized teams are working in the Institute of Physiology and the Institute of Economics.

The **Institute of Physiology** has been giving much attention to neurocybernetics since the early sixties. The aim has been to apply the methods of theoretical and technical cybernetics to get a deeper insight into the mechanisms of neural systems activity. It was necessary to form a team consisting of experts of various erudition who know about their colleagues' profession at least as much as to being able to communicate. It was also necessary to have an access to a computer equipped with special input and output devices and devices for data processing. Such a team of neurophysiologists, psychologists, mathematicians, computer experts, and engineers has been formed and it achieves satisfactory results. Some of the specialists were educated at the Institute of Information Theory and Automation.

At the Institute of Physiology, computing methods are used for automatic quantitative processing c f bioelectrical signals in nerve cells as well as in the whole brain of experimental animals or people, both healthy or diseased. Various computers and special devices were applied to these problems. Original techniques to generate stimuli with precisely defined statistical properties were developed and closed-loop control of brain processes by using electrophysiological data was carried out. All the research was successful in obtaining new scientific results regarding the mechanisms of neuron systems activity, perception, attention, sleep, motivation, learning, memory, and of brain paroxysms. At the Institute of Physiology different aspects of biomathematics are also studied with the aid of the Mathematical and Statistical Centre of Biological Institutes of Academy.

Another institute, where the cybernetic methods are applied, is the **Laboratory of Econometrics,** affiliated to the Institute of Economics. It has been active since 1963 in the basic econometric research. It studies models applicable in analyses, planning, and control of the national economy. It develops econometric methods, algorithms, and programms to analyze the models. It makes use of modern computational techniques and puts the results into practice. The research in this area has an interdisciplinary character: economy, mathematics, statistics and computing science are involved.

The Laboratory consists of three divisions: modeling of the national economy, operations analysis, and mathematical programming. The first division studies

models of the national economy with applications in planning and control. The obtained results are actualized in cooperation with the customers. The most significant results is "The model of the optimal medium-term plan: the output of model responses to changes in discount rates and capacity constraints". The second division develops methods for analysis and modification of complex information, planning and control systems using digital computers. The study "Systems analysis and synthesis", summarizing basic system approaches to the study of economic phenomena, has been completed. The third division algorithmizes the solutions to the above problems and verifies the methods developed.

The Laboratory has completed the pair method to solve distributional problems, and the programs to solve problems of bivalent and separable programming. The respective results have appeared in the journal Ekonomicko-matematický obzor (Reviws of Econometrics) and in the special series of publications.

The activity of three departments of the **Institute of the Czech Language** also falls within the cybernetic applications. They are the Phonetic Laboratory, Department of Mathematical Linguistics, and Mechanographic Laboratory. The Phonetic Laboratory cooperates with the electroacoustic experts of the Research Institute for Communication to obtain the physical parameters of the acoustic form of the speech – its analysis, synthesis and perception. The perceptive weight, redundancy, and relative substitutability of the relevant ranges of the acoustic entities are also studied. At present, the research is being done in the statistical ensembles of the language units. To employ a computer, the necessary peripheral devices, analogue/digital converters and programs have been provided. One of the potencial results is the acoustical output of the computer. The Department of Mathematical Linguistics is concerned with statistical language models, a link between linguistics and cybernetics. Using a digital computer, quantitative characteristics of large ensembles of various styles of the Czech language have been obtained. At present a largely conceived lexical and grammatical analysis of Czech texts is in progress.

Computer applications to linguistics are made in the following respects: (1) Gathering, description and storing the language data, (2) structural analysis and generating the system units, (3) documentation, verification and commentaries of literary works and (4) text checking and contractive processing of vocabulary for text reviews.

The methods of cybernetics are also applied at the **Institute of Czech and World Literature**, mostly from the point of view of the language communication.

The activity of the other institutes and laboratories of the Czechoslovak Academy of Sciences involved in cybernetics can be classified as follows: the construction and application of special devices, the application of computing techniques in research and the establishment of interdisciplinary groups studying applications of these methods in given field.

The **Institute of Parasitology**, jointly with the Institute of Information Theory and Automation, has produced a system for automatic long-term measurements of

temperature changes in the field conditions, using a punched-tape recording. Thus the data gathering is automated and the experimental research can be extended.

The **Institute of Experimental Botany** is similarly oriented. Its division for the motion-picture study of live processes has developed a number of instruments based on optical registration. This division also studies closed-loop principles governing growth of plants.

Computing techniques are in current use by most institutes and the larger of them are equipped with computing centres. The application of cybernetic and computing methods usually requires new complex and advanced approaches as well as development of special devices.

For a long time the **Institute of Solid State Physics** has been oriented in design of special purpose computers. Already since 1952 such computers were designed for application in the research of solid state materials by means of X-ray difraction, in computation of Fourier maps, etc. (For instance, special purpose computer ELIŠKA was the first computer designed and used in Czechoslovakia.) Beside that the Institute was succesfully oriented to computerization of its research work, in general.

Another institute with good results in computerization is the **Astronomical Institute**. Computing techniques are there widely used for a variety of problem for computation as well as for modeling of some processes. Obtained models serve in developing new measuring and evaluating methods.

Computing techniques are further used in the **Institute of Thermomechanics**, where the motion of mechanical systems with impacts and nonlinear systems oscillations are studied, and in the **Institute of Hydrodynamics**, where the flow of non-Newtonian liquids is studied, etc.

For some groups of related institutes of the Academy (e.g., for institutes involved in biological research) computing centres have been established. These centres are provided with specialists and appropriate equipment in order to contribute to the development of computing and cybernetic methods in every particulary area.

At some institutes, small groups or individuals promote the methods of cybernetics in their own branch. In particularly, at the **Institute of State and Law**, these methods are used to gain the scientific knowledge of the state and law, and applicability of these methods in legislative and administrative practice, in the legal problems of the national economy, state administration and administration of justice. At the **Institute of Psychology** specifically heuristics and heuristic programming of cybernetics are developed. Other areas of application of cybernetic methods in the institutes of the Academy involve historiography, the philosophic problems of cybernetics, the social aspects of cybernetics, system engineering, system theory, etc.

Cybernetics – an interdisciplinary complex of sciences – requires a close and fruitful cooperation of diversly oriented scientists with theoretical as well practical interest. In this way cybernetics contributed to the interrelations of sciences and strengthened the unity of our scientific effort.