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A New Discipline of Science ——The Study of Open Complex Giant System and Its Methodology

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Abstract: This paper introduces the conception of open complex giant system and the methodology for dealing with the system, with stress on its profound significance in development of science and technology. The authors conclude that the reductionism underlying the exact science is not suitable to open complex giant system, and the only feasible alternative is the meta–synthetic engineering from the qualitative to the quantitative.

Keywords: Systems science, Methodology, Meta–synthetic engineering.

In the last twenty years, systems science, evolving from concrete applications of systems engineering, has gradually developed into a new discipline of modern science and technology[1]. Notably in recent years a large new field emerges, i.e. the research of open complex giant system. The aim of this paper is to discuss this system and its methodology.

1. Classification of Systems

System science takes systems as its object of research. Systems exist everywhere in nature and in human society. For example, the solar system, the human body, a family, and a manufacturing enterprise are all systems. To facilitate research, systems can be divided on different principles into different class types. They can be classified as natural or man–made, open or closed, dynamic or time–invariant, living or inanimate, etc.

The classifications above are rather straight–forward, but the point of view stresses too much on the concrete intension, so the essence of the system is thereby neglected. And the essence is of supreme importance to systems science research. So a new classification has been brought up in [2] as follows:

Depending on the quantity and the interactive complexity of the subsystems and variety of subsystems contained in the systems, Systems can be divided into two large groups: simple systems and giant systems. Simple system denotes there comprising relatively fewer subsystems with simpler interrelations. Some inanimate system, such as a measuring instrument, is a small system. If the number of subsystems is comparatively large (e.g. a hundred), such as a manufacturing plant, it can be called a large system. No matter which it is, small or large, such a simple system can be studied, starting from the interaction of the subsystems, then directly synthesizing the dynamic function of the complete system. This can be called the direct method. At most, a large computer or a supercomputer is needed to process such a system.

If the number of the subsystems is extremely large (e.g. thousands to trillions), then it is called a giant system. If the variety of the subsystems is not too diffuse (several, or tens of different kinds), and their interrelation is not too complex, then this can be called a simple giant system, e.g. a laser system. Naturally, approaches for treating simple small or large systems cannot be applied to the study of such giant systems, even a supercomputer won't suffice, and no anticipated computer will have adequate capacity to meet the needs of such mode of study. Direct synthesis won't do, so the great achievements of statistical mechanics are brought to mind, where giant system consisting of billions of elements is generalized by statistical methods with details neglected. This contribution is made by Prigogine and Haken. They called their work, theory of Dissipative Structure and Synergism respectively.

2. Open Complex Giant System

If there is a large variety of subsystems with hierarchical structure and complex interrelations, then the aggregate is called a complex giant system. As examples, there are the biological system, human brain system, somatic system, geographical system (including ecological system), social system, celestial system, etc. Their structure, function, behavior and evolution are all complex and not yet well understood today. Take the human brain as an example. It has more than 10^{12} neurotic cells and their interaction is much more complex than an electronic switch. It has been noted by E.Clementi[3], the human brain is like a huge computer network consisting of 10^{12} supercomputers, each working at 1000MHz, in parallel.

On a higher level are systems with human beings as their main subsystems. For such, "open" and "complex" have newer and broader connotations. Here, openness denote energy, information, or material exchange with the outside world. To be more exact, (1) system and its subsystems exchange information with the outside world; (2) the subsystems acquire knowledge by learning. A human being is a complex giant system. Society takes enormous quantity of such complex giant systems as its subsystem. The complexity of such systems can be outlined as thus: (1) between the subsystems there are many modes of communication; (2) subsystems are of many varieties; (3) the subsystems have different ways of expressing and acquiring knowledge; (4) the structure of the subsystems change with evolution, so the structure of the system is in a state of flux.

This classification of system clearly depicts complex levels of the system. It is of great significance to research of the theory and application of systems science and this can also be seen from recent studies of social system. Studying human beings, the complex giant system, can be regarded as micro research of social systems, while in the field of macro research of social systems, it is well known that any society is of three social formations, i.e. the economic social formation, the political social formation and the ideological social formation. Social system can be divided into three integral parts, i.e. the social economic system, the social political system and the social ideological system. Corresponding to these three social formations, there should be three civilization constructions, i.e., material, political and spiritual. The socialist civilization construction should be the coordinating development of these three aspects. This conclusion is of significance both in theory and in practice. From the angle of practice, what guarantees coordinating development of these three civilization constructions is the social systems engineering. According to the definition of systems engineering given by Qian et al[4], the technique of organizing and managing the social economic system is the economic systems engineering, the technique of organizing and managing the social political system is the political systems engineering and the technique of organizing and managing the social ideological system is the ideological systems engineering. And then the social systems engineering is the organizing and managing technique which makes coordinate developments among these three subsystems and between the social system and its environment. Seeing from the reality of our reform and opening policy, not merely the economic systems engineering is necessary, but, more importantly, the social systems engineering is needed. Carrying on the economic system reform alone and not paying attention to the interrelation and interaction of the other two subsystems, the economic system reform is difficult to succeed. For example, official profiteer, some corrupting phenomena in the Party and unhealthy social tendency produced so serious impact to the economic system reform that the government has to adminster the economic environment and rectify the economic orders. All this shows that the one–track mind and piecemeal reform just does not work. Reform needs overall analysis, overall design, overall coordination and overall plan. This is the realistic significance of the social systems engineering to the reform and opening policy in China.

From examples of the open complex giant system illustrated above, it can be seen that they involved biology, noetic science, medical science, geoscience, astronomy and social science theories. So this system is a really giant field for scientific research. It is worth to point out that theories of these disciplines originally distributed in different branches of science and even in different scientific and technological domains. They are of rather a long history and they do express in some extent the idea of the open complex giant system with their own languages. The theory of the traditional Chinese medical science can be taken as one example. but today they can be summarized in the concept of the open complex giant system and even more clearly and more profoundly. This fact inspires us that the raising of the concept of the open complex giant system and its theoretical research will not only promote the development of theories of different disciplines, but also opens up new inspiring prospects for linking–up of these theories.

3. Methodology of Studying Open Complex Giant System

Up till now, researches of open complex giant system have not as yet achieved the theory from microcosm to macrocosm and there was no theory of statistical mechanics constructed from interrelation of subsystems. Then, is there any research method? Some persons thought it rather simple. They copied mechanically methods for dealing with simple systems or simple giant systems to deal with open complex giant systems. They did not notice restrictions and applicable range of these theoretical methods, but copied them mechanically, thus running counter to their desires. For example, so far as its theoretical frame is concerned, game theory in operations research is a very good tool for studying the social system, but its level attained and results achieved today is far from dealing with complex problems of the social system. The reason is that, in game theory, human sociality and complications and uncertainty of human psychology and behaviour were oversimplified so that problems of complex giant system became those of simple giant system or simple system. Similarly, this is the same reason why it was not a success when applying system dynamics and self–organization theory to the study of open complex giant system. The originator of system dynamics, J.Forrester, himself pointed out[5] that it should be prudent in utilizing his method and the convincibility of models built should be studied. However, some persons at home paid no attention to his words, but utilized it "boldly".

On the other hand, still others just raised problems of complex giant system to the level of philosophy and indulged in talking in the air that system movement was dominated by subsystems, microcosm dominated macrocosm, etc.. One typical example is " Unified Holographic Theory of the Universe"[6]. They did not see that human beings can not recognize subsystems completely, and there is deeper and finer subsystems within subsystem. If you discuss unknown with imcomplete knowledge, then what can it do? They even erroneously adanced that: "The part included total information of entirety" and "Part is entirety and entirety is part. These two are identical absolutely". This is contrary to objective facts completely.

Studies and practices have clearly proved that the only feasible and effective way to treat an open complex giant system is a metasynthesis from the qualitative to the quantitative, i.e. the meta–synthetic engineering method. This method has been extracted, generalized and abstracted from practical studies, especially of the following three complex giant systems.

1. Social system: studies and applications of systems engineering technique for social systems, such as a social economic system which would be described by hundreds or thousands of variables.

2. Human body as a system: a combined study of physiology, psychology, western medicine, traditional Chinese medicine, Qigong (a traditional Chinese meditation exercise for the healing and prevention of illness), psychokinesis, etc..

3. Geographical system: study of geographical science by synthesis of ecological system, environmental protection and regional planning.

In these studies and practices, scientific theory is usually combined with empirical knowledge and expert judgement. Empirical hypotheses (judgement or conjecture) are put up which cannot be proved by rigorous scientific methods. They are qualitative knowledge, but their accuracy can be checked on models built from empirical data and reference material, with hundreds and thousands of parameters. The models are based on experience and practical knowledge of the system. Through quantitative calculation and repeated collation, conclusion is finally reached. This conclusion is the best to be found at this stage of knowledge of reality. This is quantitative knowledge arising from qualitative understanding.

Thus metasynthesis from qualitative to quantitative approach is to unite organically the expert group, data, all sorts of information, and the computer technology, and to unite scientific theory of various disciplines and human experience and knowledge. This makes a system in itself. Successful application of the method depends on giving full play to the synergetic advantages of the system.

In recent years, some scholars proposed to use meta–analysis methods[7–10] for carrying out trans–field analysis and synthesis of informations in different fields. However, the method is not mature and too simple while the meta–synthetic engineering from the qualitative to the quantitative is the real meta–synthesis method.

4. An Example of the Application of the Meta–Synthetic Engineering

Now, we will describe this method and its application by an example from the social economic systems engineering: a synthetic study of financial subsidy, price and wage in China economic construction. This case is successful.

Since 1979, as a result of the policy of raising the purchasing prices of farm and sideline products and giving extra pay for extra purchase, income of farmers increased. This increment came from government financial subsidy. But at that time, there was no corresponding adjustment on the selling prices. The result was, with good harvest year after year, government subsidy increased rapidly, thus becaming government heavy financial burden. This was the main source of deficit in our national budget and induces a very incongruous financial problem. As a result, the rate of increase of our national financial revenue was manifestly lower than that of the national income. Percentage of financial revenue in national income decreased yearly.

Problems arising from governmental subsidy attracted great concern from the government. Departments in charge proposed the use of two economic levers, price and wage, to gradually reduce and then remove this subsidy. But adjusting the prices of retailed commodities will inevitably affect the living standards of the people. If this is accompanied by wage adjustments, then problems of financial load, market balance, currency issue and savings will be involved. These problems again affect the production, consumption, circulation and distribution aspects of the economic system.

Financial subsidy, price, wage and other directly and indirectly related economic components form an interrelated, interacting system with certain functions. Adjusting prices and wages, and then eliminating financial subsidy is, in fact, to modify and regulate the interrelation and interaction of the system, so as to make the system possess our desired function. This is a typical proposition of systems engineering.

This problem will be studied first by economists, management specialists, and system engineers. Applying their knowledge and experience, they clarify the crux of the problem, make qualitative assessment (empirical hypothesis) on ways and means to be used to solve the problem, and then put the problem in a system frame, determine its boudaries and specify the state variables, environment variables, control variables (policy variables) and output variables (observation variables). This step is of prime importance in determining system modelling concept, modelling requirements and function.

System modelling is the use of a mathematical or logic model to describe the structure, function and input / output relationship of a real system. Study on the model reflects study of the real system. Modelling procedure requires both theoretical method and experience. Real statistical data and related material are all necessary.

With a system model and the help from a computer, system and its function can be simulated. This is like experimentation in a laboratory. By means of system simulation, reaction under different inputs, dynamic characteristics and future behavior prediction of the system can be studied. This is systems analysis. Based on such analysis, system optimization can be worked out. The aim of optimization is to find out the optimum, sub–optimum or satisfactory policy or strategy to help the system obtain the desired function.

Quantitative results obtained by means of the procedure above are again put under discussion by the experts to make some decision. The result may be plausible or doubtful. If the latter, the model must be modified and the parameters readjusted. Then the procedure is repeated. There can be many repetitions until all experts agree on the reliability of the result. Then conclusions and policy proposals are made. Now, there are both qualitative description and quantitative base. The conclusions will have sufficient scientific foundation, not only as a prior assessment and conjecture. The above steps are shown as a block diagram in Figure 1.

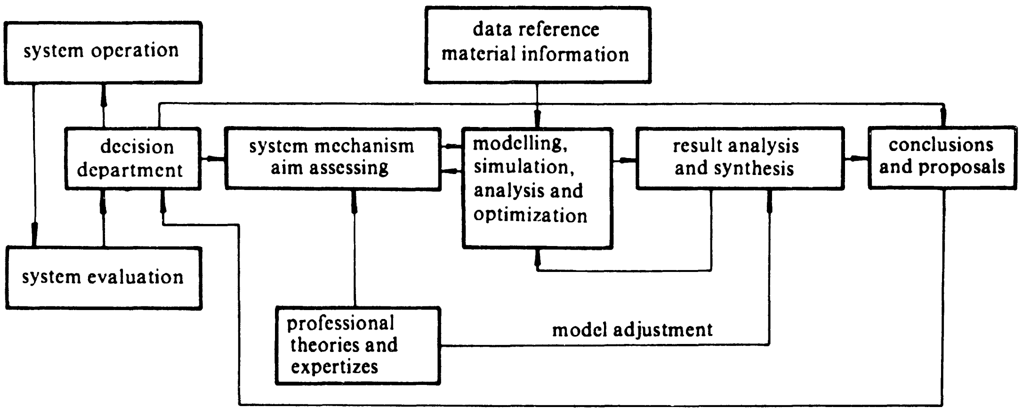

Fig. 1 Application of meta–systhetic engineering

5. Knowledge Engineering Is Applicable to Meta–Synthesis

Meta–synthetic engineering as sketched above is quite effective. In the process of solving the problem, the experience and knowledge of the expert group contributed much to its success. Expert system is a representative knowledge type system and it is a subsystem of the large system. In the above discussion, open and markedly complex giant system ranks highest in the hierarchy. System with human being, expert system and intelligent machine as subsystems must be a man–machine system. The subsystems are interrelated and have to be coordinated. Men guide and decide the key points, machines carry out the repetitive and tedious work.

The kernel of knowledge engineering is knowledge expression. That is, how to express various kinds of knowledge, such as book knowledge, relevant knowledge in special fields, empirical knowledge, common sense knowledge, etc., in a form that can be accepted and treated by a computer. Knowledge type system is different from the usual dynamic system. The distinguishing feature of the knowledge type is in solving problems by knowledge–controlled inductive method rather than precise quantitative procedure. This is because a great part of knowledge is empirical and cannot be described with precision. For knowledge type system, we cannot build quantitative mathematical models as we used to do. Only qualitative method is suitable. If the system contains some elements which can be described quantitatively, then system synthesis can only be carried out by qualitative and quantitative coordinated method. There has been a lot of work done on utilizing qualitative physics conception and model–building method to establish qualitative models and thereby study qualitative reasoning[11]. Qualitative model–building is a method of coding deep underlying knowledge, which only takes care of the trend of change like increment, decrement and invariance. Qualitative reasoning denotes operation on qualitative model and from which system behavior is understood or predicted. Up to now, work has been done on three fronts. De Kleer et al of Xerox brought out a component centered model. They consider combinability as the chief attribute of a system. Structurally, system is a combination of parts. Behavior of a system can be deduced from the behavior of its parts. They are trying to establish a qualitative physical system that can make explanation and prediction. In another front, Kuiper of the Computer Science Laboratory, MIT, proposed a constraint centered model. Thirdly, Forbus of the Artificial Intelligence Laboratory, MIT, built up a process centered model. He called the sources that induce motion and change as processes and is trying to form a theory to show the influence of process on physical procedure. The motive of studying qualitative model building and deduction is to study common sense knowledge and resolve the problems of expression, storage and deduction of such knowledge. Many experts think work on the method and theory of qualitative modelling and deduction will probably pave the way to utilize common sense knowledge. European Convention of Artificial Intelligence 1988, confers the Best Thesis Award to a paper on qualitative physical model and computational model. This indicates the expectation men placed on such study.

In fact a lot of important work on artificial intelligence is considered from the system aspect. Some maintain that study on artificial intelligence can be generalized as the knowledge of studying the computational methods of the acquisition, expression and application of various qualitative models (physical, perceptive, cognitive and social models)[12]. This is a reflection of systems science. At present, attention is paid to the synthetic trend in artificial intelligence. The Computer Integrated Manufacture System (CIMS) is an example. Product design and manufacture are two important aspects of industrial production. Each comprises many links which perform work with modern technology through man–machine interaction. Formerly design and manufacture were separately considered. Now there is a tendency to merge them together and feed back in time information relating to product quality during manufacture to the design department, thus making the whole production process flexible and effective, and assuring high grade production. This scheme of over–all planning of the design and manufacture, and even management and sales activities is exactly the embodiment of synthetic thought of an open complex giant system.

In short, after extending the conception of "openness" and "complexity" of a system, the understanding of the system becomes deeper and the range of contents generalized wider. This width is obtained by abstracting and generalizing the development of modern science and technology and especially the newly emerging knowledge engineering, and has a sound basis. After expounding the proposition that the open, extremely complex, giant system is in the highest hierarchical level in the system classification, the two large fields of systems science and artificial intelligence is in fact interlinked. Thus all kinds of intelligent systems characterized by knowledge, such as cooperative artificial intelligence systems, distributed AI systems, and real–time intelligent systems are grouped into a unified distinct category. This facilitates the establishment of theoretical basis to the open complex giant system. This is the inevitable outcome of the development of modern science.

6. Implication of the Study of Open Complex Giant System

From the above, characteristics of the meta–synthetic engineering from the qualitative to the quantitative can be summarized as follows:

1. Based on the characteristics of complex mechanism and large number of variables of the open complex giant system, qualitative study and quantitative study are united organically; qualitative comprehension is raised to quantitative comprehension.
2. Owing to the complexity of the system, scientific theory and empirical knowledge must be combined, and piecemeals of knowledge of the object world must be collected to solve problems.
3. With system in mind, various scientific disciplines are studied as group.
4. According to the hierarchical structure of complex giant system, macroscopic study and microscopic study are united.
5. Application of this method should be supported by a computer system, which has not only the function of management information system (MIS) and decision support system, but also the function of meta–systhesis. Therefore, we have to use the newest techniques such as KE, AI, information technique, etc..

It is these characteristics that make the method capable for solving complex problems in the open complex giant system. Therefore it is of great significance.

What modern science and technology explores and studies is the whole objective world, but when studying different problems in the objective world from different sights, with different viewpoints and methods, different science and technology domains formed in modern science and technology. For instance, natural science studies objective world from the view of material movement, different levels of material movement and relations between different levels; social science studies objective world from the view of studying human social movement and the effect of objective world upon the humanity; and mathematics science studies objective world from the view of quantity and quality and their mutual conversion.

In the same context, systems science studies objective world with systems viewpoints and systems methods. As one of science and technology domains, systems science takes systems as its study object from its applications to the basic theory research. In macro world, i.e., on our earth where lives and living beings exist, human beings and human society emerge and there is also the open complex giant system. This kind of system exists in cosmic world too. For examle, the Milky Way system is an open complex giant system. Thus, the open complex giant system is beyond the macro world into a broader field. Therefore, the open complex giant system and its research is of common signifigance. However, as mentioned before, all the past science theories could not solve problems of the open complex giant system. As for the reason, we can find it in history.

It is well known that rules governing the living system and the inanimate system are distinctly different. The inanimate system obeys the Second Law of Thermodynamics, the system always intrinsically tends to be in a state of equilibrium and disorder, and disorder will never automatically change to order. This is the irrevocability and stability of equilibrium state of the system. But the living system is just the reverse, evolution of living things and development of society are always from simple to complex, from low–level to high–level, and the system becomes more orderly. Such system can spontaneously form an orderly and stable structure.

Is there any innate relation between these two contradictory systems? In the sixties of this century, the appearance of the theory of dissipative structure and synergism proposed a scientific frame for solving this problem. These theories consider rules brought out by the Second Law of Thermodynamics refering to isolated systems (no material or energy exchange with the environment) in a state of equilibrium or near equilibrium (state of linear nonequilibrium). But the living systems are usually open systems and are far away from equilibrium (in a state of nonlinear nonequilibrium). Under these conditions, the system brings in negative entropy through material and energy exchange with the environment. Though positive entropy is produced inside the system, the net entropy decreases. Under certain conditions, it is possible for the system to change automatically from the originally disorderly state into a state of order with respect to time, space and function. This, Prigogine called a dissipative structure. Thus without contradicting the Second Law of Thermodynamics, the theory of dissipative structure links up the innate relation between these two system[13]. Haken made a further step forward by pointing out, the crux of system turning from disorder to order is not whether the system is in equilibrium or not, nor how far it is from the state of equilibrium, but is in the interaction between the subsystems making up the system. By their nonlinear interaction, they cooperate and, under favorable conditions, spontaneously produce a stable and orderly structure. This is a self–organizing structure[14].

This achievement of modern science in recent 20 years is very important. It expounded the riddle which has puzzled scientists for a long time. But the success of the theory of dissipative structure and synergism made some persons to be over–optimistic. They thought this quantitative methodology based on the reductionism that underlies the modern science can be applied to the open complex giant system too but failed.

In the history of scientific development, the science with quantitative research as its main method once was called "exact science" while the science with speculation and qualitative description as its main method was called "descriptive science". Natural science belongs to exact science while social science to descriptive science. Social science is a kind of science which takes social phenomena as its studying objects. Complexity of social phenomena makes it difficult to describe quantitatively and this is possibly the main reason why it cannot become exact science. Though scientists did great effort to make social science to transit from descriptive science to exact science and achieved some results, for instance, in the field of economic science. But the entire social science system is far from exact science.

From the above discussion, we can see that the study of open complex giant system and its methodology is, in fact, to collect the great amount of dispersed knowledge into a whole structure. It is a leap from quality to quantity. When each facet of the problem has been thus studied, the accumulation of the results will heighten our knowledge of the problem as a whole and make another leap.

The famous German physicist Max Planck realized that science is an inherent entity and its being resolved into isolated entities does not depend on things themselves but on limitations of human cognitive ability, that there actually exists an interlocking chain from physics to chemistry and through biology and anthropology to sociology, and that such a chain that can not be ruptured anywhere. Researches in natural sciences and social sciences covered the whole chain, but study on systems science is a kind of science that connects this chain.

We call this process the unification of natural science and social science. We can say that the research on open complex giant system and its methodology establishes scientific and feasible approaches and methods for realizing this unification.

In conclusion of this discussion, we need to point out that the meta–synthetic engineering method from the qualitative to the quantitative referred here not only is the sole feasible method for dealing with and studying open complex giant system, but also can be used to deal with millions of mass′s individual opinions, congressmen′s suggestions and motions and experts′ views, and even decisions of individual leaders thus attaining really the goal of *making a mickle with many a little*. Its significance is far above the progress and development of science and technology.

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Upon Returning to his homeland in 1956, he began a second career as President of the Academy of Rocket Research and then as Vice–Minister of the Seventh Ministry of Machine Building until 1970. From 1970 to 1982, Dr. Qian was Vice–Minister of the Commission of Science, Technology and Industry for National Defence (CSTIND). After 1982 he served as Vice–Chairman of the Science and Technology Committee–within the CSTIND, and then as Chairman of China Association for Science and Technology (CAST). He is now Vice–Chairman of the Chinese People′s Political Consultative Conference.

Dr. Qian has been the technical leader in China′s pioneering rocket and space programs. He has made great and path–paving contributions to space technology and to systems science and engineering. In 1989, he won the Rockwell, Jr. Medal awarded by International Technolgy Institute, Pittsburgh, USA, for excellence in technology, and is known as a man of the World Level of the Hall of Fame for Engineering, Science and Technology. He has written numerous articles for publication, and given an enormous impetus to the study of theory and methodology of systems science and engineering.

Yu Jingyuan graduated in mathematics from Jinling University in 1960. Afterward, he started his career as an engineer and a student for the China′s space undertaking and social progress. From 1982 to 1983, he was a senior visiting fellow at Population Institute of East West Center, Hawaii, USA. He serves concurrently as a professor for the Xiamen, Fudan, and Northern Jiaotong Universities. He authored or coauthored over 100 technical paper and 13 books in the fields of cybernetics, systems science and engineering, and interdisciplinary exploration, including Population System Control (Springer Verlag, FRG, 1988), Population Control in China–Theory and Application (Preager, New York, U.S.A, 1985), Mathematical Theory of Population System (Pergamon Press, to be published), etc. He is member of the Editorial Board of Progress in System and Control Theory (USA), and member of the Council of Asian Forum for Development and Population Studies (India). Prof. Yu is also member of the Chinese People′s Political Consultative Conference.

Dai Ruwei graduated from Beijing University in 1955, and worked on engineering cybernetics、optial control、character recognition at the Institute of Automation, Chinese Academy of Sciences, from 1957 to 1979. From 1980 to 1982 he was a visiting scholar at the School of Electrical Engineering, Purdue University, where he worked on pattern recognition as well as artificial intelligence. He has published more than 80 articles in China and abroad. In 1991, he was elected to a member of Chinese Academy of Science. Currently, he is a professor of Institute of Automation, Chinese Academy of Sciences, a honor professor of several Universities in China, and is the chairman of the Academic Committee of the National Research Center for Intelligent Computer System. He is also the chief editor of the Chinese Journal of Pattern Recognition and Artificial Intelligence. His interests are in pattern recognition, artificial intelligence and noetic sciences.