Decision Making and Automation

Concept, Algorithm, Decision

(A SOVIET VIEW)

V. V. DRUZHININ, D. S. KONTOROV
MOSCOW 1972

TRANSLATED AND PUBLISHED
UNDER THE AUSPICES OF
THE UNITED STATES AIR FORCE
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ИДЕЯ, АЛГОРИТМ, РЕШЕНИЕ

(ПРИНЯТИЕ РЕШЕНИЙ И АВТОМАТИЗАЦИЯ)

Ордена Трудового Красного Знамени
ВОЕННОЕ ИЗДАТЕЛЬСТВО
МИНИСТЕРСТВА ОБОРОНЫ СССР
МОСКВА — 1972
Concept, Algorithm, Decision is the sixth volume in the "Soviet Military Thought" series translated and published under the auspices of the United States Air Force. The original Russian edition was published in 30,000 copies in late 1972 by the Military Publishing House of the Ministry of Defense of the USSR.

Soviet military writings assert that the "revolution in military affairs" is currently in its third phase. Having acquired nuclear weapons, and the means to deliver them, the current phase is concerned with military cybernetics—the science of effectively controlling the armed forces. The motivating thesis of this book is that recent dramatic increases in the speed, complexity, and data base of military decisions, plus multiplication of variety and flexibility of available options, call for urgent improvement in decision making tools for the control of men and weapons. The stated goal of the book is to "contribute . . . to the development of the theory and technique of decision making," with particular reference to the problems of automating the control and management of military operations.

The book is structured in three parts: Method, Means and Technology. "Method" covers conceptual models of thinking; the distinction between informational decisions, organizational decisions, and operational decisions in a military context; alternative approaches to making these decisions; group dynamics of the decision making process; and limitations of unaided intellect. The "Means" part addresses a variety of formal aids to decision making. The "Technology" section is devoted to computer technology—its intrinsic capabilities and modes of use for military decision making.

Concept, Algorithm, Decision is an attempt to integrate ideas from philosophy, psychology, social science, mathematics, and linguistics into the technical and theoretical armory of the military commander and his staff.

The authors possess impressive backgrounds. General-Colonel V. V. Druzhinin, Doctor of Military Science, is a former Deputy Commander-in-Chief of P.V.O. Strany (Air Defense of the Country) and has been a Deputy Chief of the General Staff of the Soviet Armed Forces since at least 1970. Colonel-Engineer D. S. Kontorov is a Doctor of Technical Sciences. The author of the Foreword to the Russian Edition, General
of the Army, S. M. Shtemenko, is a First Deputy Chief of the General Staff of the Armed Forces, as well as the First Deputy Commander-in-Chief of the Joint Armed Forces of the Warsaw Pact Nations.

*Concept, Algorithm, Decision* is listed as recommended reading in “The Soldier’s Bookshelf” section of the 1974 *Calendar of a Soldier*. The Soviets intend that it be read by commanders and staff officers.

*The translation and publication of Concept, Algorithm, Decision does not constitute approval by any U.S. Government organization of the inferences, findings and conclusions contained therein. Publication is solely for the exchange and stimulation of ideas.*
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The title of the book—*Concept, Algorithm, Decision*—seems narrowly specialized, and when I was asked to write the foreword to it, my first impulse was to refuse. Having read several pages, however, I was impressed with what the authors had written.

The book forces one to think. It focuses attention on one of the most modern and important problems, namely automation of control processes, improvement of and search for methods of supervision. In our age, the age of scientific and industrial progress, the solution of this problem is an urgent matter.

The book explains to the reader how mathematics, linguistics and other ancient classical sciences in cooperation with new sciences and modern technology can help man better control social processes, including the preparation and conduct of military operations. The authors use a rigorous scientific approach, but present the most complex problems of the subject with great simplicity and accessibility. They avoided unfortunate didactics undesirable in relation to our thinking reader. At the same time, the book is nonfictional, the text is interesting, and in terms of presentation occasionally resembles science fiction.

During the years of rapid scientific-technical progress, problems of the relation of man to technology have become very acute. Many new problems arose in connection with the adoption of scientific achievements. This process was accompanied by the invasion of technology into the realm of thought and cognition. It became clear that machines could render creative assistance to man. Scientific and technological advances also increased technological capabilities, fulfillment of which requires a great deal of time, and also patient labor of scientists and specialists, literally in all fields of human endeavor.

The book is an asset for any profession, even though it is written primarily for the military reader. The book should be very beneficial, since it raises important and complex questions concerning the role of the commander and his staff, problems and character of automation of control processes in the armed forces. It contributes much to an understanding of the specific features of the commander's job, manifestation of his mind and will, of his relations with the staff. The text includes numerous intelligent thoughts on how our "electronic friend" can become a consultant and assistant to the military commander.
The book justifiably emphasizes the problem of automation of processes related to the development of the required data for decision making, which is, as is known, the basis of military management. The importance of decision making has increased considerably, military situations, in the authors’ words, have become more complex and the degree of data uncertainty has increased.

The search for the best methods of making intelligent and fruitful decisions and scientific investigations of their inner essence are being conducted steadfastly and vigorously around the world. However, the works in which the various aspects of this problem, namely military, social, technical, psychological, etc., are synthesized, are very few. Even fewer works have been written at the modern scientific level, which are at the same time accessible in terms of the nature of presentation to the military community at large. The question is still discussed from different points of view in terms of general considerations and analysis of examples. Meanwhile there is an ever increasing need to understand the essence of these problems (and consequently, to some extent, the essence of human thought) with sufficient completeness and specificity: commanders and their staffs require a thorough understanding of the methodology, scientific tools and techniques of decision making.

The statement “to lead means to foresee” has a profound meaning for the military leader. Without foresight it is impossible to arrive at a decision which, on the one hand, embodies an indisputable rigorous conclusion made on the basis of military science and data from situation analysis and, on the other hand, is a willful act, performed by the commander with consideration of personal ideas and views, military experience and intuition.

The correct relationship between scientific (“intellectual”) and volitional aspects of a specific military situation can be found only by means of Marxist-Leninist materialistic analysis of the basic factors that influence the decision making process. To support this the authors unfold before the reader the total diversity and complexity of modern warefare. They show that the commander deals with many indices, factors, details, often obscure and, at first glance, insignificant, but on which depends a great deal. In their evaluation of a situation they emphasize establishment of the relations between facts, determination of the laws in these relations, and on the basis of these laws reveal the thinking of the enemy. Limited or insufficient consideration of the facts in their entirety and interrelationship holds great danger. V. I. Lenin wrote: “In the field of social phenomena no measure is more common and more incomplete than seizing on individual facts... Facts, if taken in their entirety and in their interrelationship, are not only ‘stubborn’ but are also irrefutably conclusive.”

However, it is not a simple thing for the military commander to analyze an abundance of facts. The volume of information that staffs must process has increased manyfold since World War II, and the time allowed for decision making has decreased manyfold. As a result the requirements on the "brain capacity" of commanders and staffs have increased vastly. To meet these requirements by simply expanding the administrative apparatus is fundamentally impossible, since this would require an inordinate increase in the number of headquarters. Organization of efficient operation within such vast management offices would become a very difficult task.

The only escape from this incompatible situation lies in the extensive application of automation, primarily computers. Modern information technology enables us to transmit, receive, re-request, check, evaluate and display in graphic form a mass of data within a sufficiently short processing time. Even more complex logic processing of data is being done: comparison, evaluation and generalization. All this makes it possible to liberate people from accounting and other difficult but mechanical work, and to turn the intellectual potential of the commander to the solution of fundamental military management problems. Complete liberation from low level auxiliary jobs not related to intellectual activity is the measure that can facilitate an increase in the creative activity of commanders and staffs and increase the effectiveness of military management.

This, as the authors quite correctly write, is only one aspect of the problem. The other aspect is the fact that information technology does not simply help the commander and his staff, but also stimulates the development of collective military creativity, in which the largest group of people, including those separated by great distances, can participate.

The adoption of automation in the management process involves many new complex problems and unanswered questions. Chief among them is the problem of complete utilization of the experience and intellect of man and integral combining of it with the speed of the computer. The authors of the book correctly call this the "problem of the century." They see the solution of the problem in the well planned, step by step, thorough analysis of control functions in order to formalize these functions through an accumulation of knowledge and experience and to send them on in this form for solution by technical means.

The authors approach the problem of the preparation and making of decisions from the technical systems point of view. They proceed from the position that a single "man-machine" system is more perfect than "man" ("people") alone or "machine" alone. In addition, automation considers primarily practical problems. In their opinion, the development of any technical system should pass successively through various stages from the simplest to the most complex. This should be done under normal military operating conditions. Large programs often are not taken
to their conclusion because the principle of step by step development is replaced by the “all or nothing” principle. In this case, because of the tremendous number of new problems, technical and other difficulties, time is wasted, the tasks and requirements are changed, and nothing useful results. The initial concepts embodied in a large system gradually become outmoded and work ceases. Therefore the authors quite correctly do not reach for the impossible, but rather proceed step by step. For this purpose it is necessary to formulate distinctly the goal of each step and to evaluate the actual capabilities without losing sight, of course, of perspective. The results that are achieved may be built upon gradually.

The problem of introducing automation systems in the management process involves a variety of sciences and industries: philosophy, psychology, mathematics, computer technology, communications systems, engineering psychophysiology, linguistics, etc. It may be solved through compulsory dialectic unification of the processes of developing new technological systems and thorough preparation of personnel in their operation. Improper personnel training results in not using the full capabilities of automation, and unskilled commanders and staff officers, instead of helping themselves, only burden themselves with new concerns and worries. Improperly structured technical systems cannot perform as expected.

Automation systems are components of a weapons system. They should be efficient, reliable and easy to use. Like any weapon, they must be mastered completely. It is essential to know the system and the principles of military application, to become accustomed to them and, if you desire, to love them. In only this way is it possible to get the most from them. The capabilities must be analyzed not only in the broad problematic sense, but also in the specific, applied, narrowly specialized sense. Management automation processes, as borne out by scientific forecasting, will develop even more rapidly, requiring continuous attention on problems of analyzing their properties and improving the qualifications of the servicing personnel.

As always in the development of new forms of weapons, we are now faced with complex problems of the character and volume of knowledge that the commander must possess in relation to automation systems. The commander indisputably has control of various weapons systems, including technical ones. Given the enormous variety of modern weapons systems, of course, neither the commander, his chief of staff, nor the operator is capable of complete mastery of knowledge and skills needed for all forms of weapons. There is no need for this in the presence of automation systems. All required reference data may be requested in any degree of detail and may be obtained in the form most suitable for visualization and perception with the aid of modern information systems. The commander obviously must know operational art, tactics and so-called combined systems, or system technology knowledge. Thorough understanding of military science and art, combined with knowledge of
technological systems, enables the commander to state the overall problem correctly, determine and distribute special problems among his subordinates and supervise their execution. The holding of such knowledge and the ability to use it, in addition to a broad military and political outlook, military regulations and personal qualities, enable the commander to supervise narrowly specialized technologists with competence and wisdom.

In order to exercise proper leadership, military commanders must have more than just military knowledge. They also need professional skill, intuition, experience, developed and refined by years of work, at the cost of great mental and nervous stress. Profound mental work, particularly under combat conditions, requires great self-discipline along with sufficient freedom and extensive opportunity for communicating with subordinates, chiefs and comrades. It requires continuous influx of data on the situation and detailed, comprehensive analysis of these data.

The subject of this book is how to achieve this goal, what are the best ways of creating the proper conditions for successful command and staff activity.

The book embraces a wide range of problems from Marxist-Leninist gnosiology and military conceptions to technical systems and mathematical methods of situation analysis. Such a wide practical range reflects the true picture and actual state of the art. The problem of decision making is discussed from several points of view. Many examples are given as an aid to explanation.

The book is not altogether an ordinary one. It contains neither irrefutable assertions nor final recommendations. The authors do not hide fundamental difficulties, but rather stress them, formulating and representing them in a form suitable for future military technical research. They advance several new concepts and fundamental positions, not necessarily workable, perhaps, and in certain cases argumentative, but undoubtedly worthy of future discussion in military, engineering and scientific communities. The results of independent investigations conducted by the authors in the field of the theory and practice of decision making occupy an important place in the book. These findings do not fall out of context, but comprise an integral part of the book.

The 24th CPSU Congress placed special emphasis on problems of management and announced practical measures for improving its structure, methods and style. The new requirements imposed by the Party pertain entirely and completely to our Armed Forces. The revolutionary transformations of the army and navy call for a scientific approach to the solution of problems of further improvement of military management. The time for extensive adoption of automation in the entire chain of command has arrived. This book renders assistance in attaining this important goal.

General of the Army S. M. Shtemenko
Introduction to the Russian Edition

Freedom of will, consequently, is the same as the ability to make decisions with a knowledge of the problem.

F. Engels

The 24th CPSU Congress placed great emphasis on the management and utilization of new technical systems. It is stated in the resolutions of the Congress: “Undertake efforts to develop and adopt automated planning and management systems in various fields . . . bearing in mind the development of a state-wide automatic data collection and processing system . . . Ensure from the outset adherence to the principal of organizational, methodological and technical unity of the system.”

The explosive development of the military-industrial complex posed new problems; one of them is decision making. The swiftness of military actions, enormous volume of various information, colossal responsibility, which in many cases takes on a nationwide and even worldwide character, finally the need to have complete guarantee that a decision under all circumstances will be arrived at and implemented by a given period—all of these and many other factors determine the activity of the commander. It is widely known that effective management of armed forces under modern conditions is possible only with the aid of automation systems. The Minister of Defense of the Soviet Union, Marshal A. A. Grechko, remarks: “The problem of mastering the scientific methods of military management on the basis of new technical systems is exceedingly urgent. Military management must be improved hand in hand with scientific and technical progress.”

In spite of the fact that the world literature abounds with publications on automation and new achievements in cybernetics, delay is per-

1 Materialy XXIV s’yezda KPSS (Materials of 24th Congress CPSU), Moscow, Politizdat, p 298, 1971.
2 A. A. Grechko, Na strazhe mira i stroitel’stva kommunista (On Guarding Peace and the Building of Communism), Moscow, Voyenizdat, p. 57, 1971.
ceived in the development of the ideological aspect of the problem. The trend toward "total" automation of management, which saturates scientific-technical propaganda, is not always wholeheartedly supported, and sometimes considerable skepticism is expressed. The "automaters" and intellectualists have been engaged for a long time in a discussion that goes something as follows:

The former: "Here you have the cybernetic industry and its capabilities, so use it. If the capabilities are inadequate tell us what you need and we will do it."

The latter: "We are ready and want very much to use cybernetics and you are welcome to expand its capabilities. We place great value on the computer. But tell us how it will help us to solve management problems and prove that it has the advantages which you say it has. Otherwise it will be hard for us to understand how to use it."

The former: "Such statement of the problem is unacceptable. This is not our field. Take the computers and learn how to use them; then the advantages will become obvious. Otherwise let us know what other equipment you need for your problems."

The latter: "To produce a positive effect the equipment must possess certain properties. Apparently you don't know very well what these properties are, because you ask us what we need. But in order to answer this question we must know what you can do and particularly for what purpose."

The discussion returns to the starting point.

The offer and the request are measured in different units and it would be unwise to see in this fact simply conservatism on the one side and unfounded optimism on the other. And perhaps in certain cases there is justification for the opinion that there are workers who feel that cybernetics is being pushed onto them by an "aggressive" group of engineers who exhibit a technocratic tendency. Quite often, actually (especially in the foreign literature), the use of terms "cybernetic management," "pushbutton warfare," and even "computer civilization" justifies a certain amount of conflict between the sides. Soviet military science long ago exploded the pragmatic ideology of "pushbutton warfare," and this ideology could hardly have any serious psychological impact on either side of the discussion. But the problem of automation, and we are talking about automation in the broad sense, brings us face to face with several technical, social, esthetic and psychological problems that must be resolved.

Everyone agrees that automation should lighten and ennoble man's labor; most people are in favor of delegating some of their functions to automata, but no one can yet determine the limits of their capabilities and benefits. This is the essence of the problem.

The practical aspect of the matter is characterized by a conflict between two different trends. The first was fostered by successes in the
development of the computer and its overwhelming superiority over man in terms of its capacity to compute. It has been assumed that the "brain" machine is capable of doing anything that man can, and even better. Consequently the electronic brain can replace man in all fields, especially in the spheres of administration and operational management. There is a group of scientists and engineers (sponsored and supported by government agencies of several capitalist countries) who propound complete automation of intellectual labor, relegating to man (though for a time) the task of developing computers and programming their functions; the future of man is viewed as sweet oblivion, a utopia, not even burdened with thought that the species Homo sapiens performed this task, created its successor and gave it dominion over nature.

The second tendency is based on worship of the exclusive capacity of mankind for creativity. Creativity is carried to the extreme—incomprehensible, unattainable—possessed by the human race alone. Since the only tool of cognition and creativity is thought, an attempt to understand thinking with the aid of thought itself is regarded as self-absorption, which can have no outcome and no result. This tendency, no less decisive than the first, consists in the worship of human intelligence, which alone is capable of making decisions and guiding the actions of people.

Both tendencies to place technology in opposition to man are very old. The development of a new revolutionary field of technology has always been accompanied by excessive enthusiasm and danger. The invention of the steam engine produced both a wave of dreams of displacing man from productive labor and "robot" propaganda. At the same time the idea emerged of the physical wasting away of man, which was inevitable when the need for physical strength vanished. We now know how ridiculous those fears were. True, the adoption of power machinery was accompanied by many tragic events, fostered by flaws in the social structure. But, of course, no "displacement" of man ever took place. Nor did physical degradation occur: modern man is taller, more diverse in terms of mental development and physically stronger than his predecessor, who for thousands of years served as the only source of productive energy. After developing other sources of energy man changed the character of his activity and because of this benefited and became richer in every sense (and greater in terms of his capabilities). This is a rule, a law, departures from which are traced only to the abnormal components of the feudal capitalistic structure, and are not related to the laws of biology, technology and social evolution.

Now technology is intruding in the holy of holies—in the realm of intelligence, consciousness and self-awareness. Nothing like this has ever occurred before; while before the invention of the steam engine man cognitively used and controlled the energy of animals, water and wind without sensing anything unusual in this, in his mental efforts he became accustomed to complete self-reliance. It is not surprising that when the
capability of computers to perform functions that could not be characterized other than as intellectual was discovered, the horizons of hope expanded without bounds. The opinion arose, and prevailed for some time, that the brain is a computer with enormous capacity, and human genius is nothing more than super speed. It was then learned that this is not so, and that the simplest brain is much more effective than the modern computer and that their functional principles differ significantly. The oversimplified concept of the mechanism of thought was incorrect and unfruitful. Although the decisive and successive adoption of the computer industry in all spheres of mental activity continues (and proceeds largely independent of discussions), we find that the computer cannot even approach problems which man is capable of solving. This gave rise to consideration of two types of problems: computable and noncomputable, or “precise” and “imprecise.”

If the problem is related to the performance of some, let us say, very complex calculation (i.e., operations with numbers), or it may be reduced to such, then it is considered to be more accessible to the computer than to man. If the problem contains elements of intuition, common sense, strange (or insufficiently formulated) experience or conjecture, then the computer is said to be powerless and only man can handle such a problem. Since the overwhelming majority of problems of behavior and control are of precisely this character, the conclusion is drawn concerning the limited applicability of the computers in this realm; in the extreme case they play a very insignificant role. Here (explicitly or implicitly) there is acceptance of the thesis that intellectual processes are beyond cognition and are impossible to reproduce artificially.

The main arguments advanced against the use of computers for solving problems of human behavior are the following: “the computer may become confused and make mistakes”; “the computer is irresponsible,” and finally, “the computer operates only according to prescribed program and it is incapable of creativity.”

The naïveté and obstinacy of the first argument are dumbfounding. If we compare and analyze the actions of any man, we find that: 1) many, if not most of them cannot be regarded as the best; 2) they are often erroneous; 3) some actions are simply stupid.

Lack of information, lack of time, inability, passion and stubbornness push us to decisions and actions which not only cannot be justified, but cannot even be explained from the standpoint of common sense. Military history abounds with examples of such human behavior, and the bitter sorrows for mistakes and the price paid for them rarely prevent new (and similar) mistakes. It is hard to say which is more surprising: the unexpectedness of mistakes, sometimes made in spite of the obvious facts, or the obstinacy with which infallibility is advocated. Even in difficult situations, of course, the fraction of explicitly contradictory decisions is small. A much greater fraction of decisions cannot be regarded
as optimal: there is some truth in the saying that it is our misfortune that we cannot perform our actions twice. There are even more typical, "ordinary" decisions. There are not very many great decisions, let alone ingenious ones.

Thus, the question as to who is confused more often, man or computer, should still be considered unanswered.

A special topic remains for discussion, concerning creativity. This question is the subject of never ending discussion. The invention of the clock, radio and differential calculus were acts of the highest creativity, the greatest achievements of human genius. Clocks and watches are now made on assembly lines, radios are put together by elementary school students and differential calculus is used by countless people. The result of creativity is transformed after adoption into technology; military creativity is no exception.

There is plenty of technology in the military science. Should human intellect be expended on it? At this time the construction of radio receivers in accordance with prescribed technical requirements is done by the computer, and engineers perform fundamental improvements. The following requirement also applies to military science: liberate the commander from technology for true creativity. There is a real need for this. Under modern conditions the commander has tremendous operational and tactical freedom. The yield range of weapons extends from hundreds to billions of joules, speeds vary from kilometers per hour to kilometers per second, and the time of continuous action against an enemy ranges from fractions of a second to months and even years (radioactive warfare). The proper use of this freedom and the choice of the best means of military actions are exceedingly complex and may be beyond the grasp of man.

The computer actually operates according to a program. However, first of all, man also operates by a program, even though it is incomparably more general, flexible and much more capable of self-improvement. Secondly, it turns out that the computer can help human creativity by stimulating it. In any case it is clear that the question of creativity is a practical problem that can be solved only through specific activity, and not as a result of theoretical discussions.

Each of the stated tendencies is based on serious argumentation, including experience, and neither of them claims higher priority. Wherein, then, lies the truth? It is very tempting to assume that the truth lies somewhat in between: man does a little, the computer does a little, there is some intuition, a bit of arithmetic, and then, on the basis of the actual breakdown of the situation it is possible to divide the spheres of influence of man and machine and thereby answer the question, at least for the near future. In military science such a compromise position is considered unjustified and incorrect. The range of command activity and responsibility are too great to permit compromise.
Marxism-Leninism teaches us that the truth lies not in conciliation, but rather in the dialectic unity of contradictions. In the case at hand we are speaking of combining the capabilities to stimulate dialectic development. This concept is still no more than a philosophical thesis. Before it can become a leading idea it must be recognized and materially supported. Eventually, in human thinking, personal and social, these contradictory tendencies have always conflicted: sober calculation and creative fantasy. And if throughout history the proponents of fancy, even creative people, have suffered because of notorious “common sense” and primitive calculation based on it, then in the short-term triumphant existence of the new factor of civilization—computer technology—we may also observe the opposite tendency: an attempt to artificially restrict not only the range of application of computers, but also research and investigation in this field, pleading the case for fantasy and creativity.

Automation does not replace and does not supplant creativity. Automation carries creativity to a higher, more general level. It utilizes and extensively applies the results of creativity, makes their application accessible and converts it to productive and military force. The position of automation in the spiral of development is illustrated in Figure 1.

Figure 1. Position of automation in the general process of development.
In order to formulate the basic ideas that are discussed in this book, we must begin by clarifying concepts and terminology. What is a decision? The Great Soviet Encyclopedia (2nd edition) gives the following definition: “A decision is one of the necessary elements of voluntary action . . . and of means of its implementation. A voluntary\(^1\) action presumes preawareness of a goal and of means of action, mental completion of the action prior to the physical act, consideration of the reasons for or against its completion, etc. This process is concluded with the making of a decision.”

And so, a decision is **first of all an action**, i.e., some process that consists of several individual acts or procedures. This is volitional action: the volitional factor is one of the elements that guide the decision making process. The decision may vary, depending on the volitional factor. Consequently a decision is not unique. The purpose of the volitional factor is to select one variation. A decision is not the proof of a mathematical theorem and is not a conclusion, since neither requires the participation of will. Strictly speaking, the expression “to solve a mathematical problem” is incorrect, since this expression connotes arriving at a conclusion on the basis of initial data (conditions of the problem). The volitional element does not exist here (if the willpower required for forcing one to think is not taken into consideration). There is only one conclusion (if the problem is formulated correctly).

Let us return to the GSE [Great Soviet Encyclopedia] “Conclusion . . . —a judgment, the inevitable or possible consequence of other judgments (premises or prerequisites). A conclusion and premises taken together are a form of thinking, called deduction.”

We are speaking here of consequence, i.e., of the inevitable or possible result of the combined effect of premises (conditions). A conclusion is a judgment. We will recall (see GSE) that “a judgment is a thought, in which something about something else is affirmed or denied. That which is affirmed is called the object of judgment. That which is affirmed or denied about the object of judgment is called an attribute. The object of judgment may be: 1) Any physical object . . . 2) Any ideal object . . . 3) Any linguistically well-defined thought. . . . Any judgment may be broken down into a subject, predicate and copula. The subject is knowledge about the object of judgment. The predicate is knowledge about the attribute of the object. The copula is knowledge about whether the attribute belongs to the object of judgment or not.” A conclusion of a mathematical theorem is based on premises—axioms or other theorems. In this formulation there is no volitional factor and no problem of choice in the conditions of uncertainty. This formulation contains rigorousness, logic and sequence of discussions. Given a certain collection of initial

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\(^1\) “Volition” will be discussed in Chapter 7.
data (premises) it is possible to make a unique conclusion. The presence of incompatible conclusions signifies that the problem is contradictory and no conclusion can be derived. Two things that negate each other cannot be affirmed. In this sense mathematical problems require not a solution, but rather a conclusion. If the need for hunting and guess work are related to the solution of a mathematical problem, then uniqueness of the result is related to their conclusion. In complex problems it is helpful to stress the former, and therefore we will say “solve the problem,” i.e., solve in the sense of finding a method. In simple problems the word “solve” has a conventional meaning: we speak here of a conclusion the reaching of which requires simply a knowledge of a rule and how to use it.

The solution of a mathematical problem involves the need for hunting and inability (if we ignore basic examples and exercises) to state the exact rule for obtaining the result. The absence of such a rule (algorithm), the use of guess work, skill and experience justify the use of the word “solution” for mathematical problems. Further, solution presumes realization beforehand of the goal and means of action. What does “realization” mean? Apparently this is a process that is based on external information about the goal and means of action. However it is not a simple transformation of information, but a more complex act that permits comparison and tying together of the goal and means. In many cases the goal may be given, and then the process whereby it is realized consists in perceiving what is given. There is information about the means and it must be perceived and understood. The main thing, however, is to realize the relation between the goal and the means, their dependence on each other and the dialectics of interaction. In other cases the goal is not given and it must be determined (or at least clarified). Then realization of the goal consists in a willful act. The number of possible goals (if these goals are formulated beforehand) may also be very large, essentially infinite, if we bear in mind the innumerable small differences between two goals.

The space of goals, like the space of situations, may be infinite, i.e., the number of possible variants of a given goal is so large that there is no exact means of determining or selecting the best variation. In cases when we encounter infinity (or a very large dimensionality), volition enters the problem, i.e., volition of man, volition of the commander. Volition also enters in those cases when there is no rigorous method of unique solution of competing alternatives, even when their number is finite and small.

But this rather obvious position, strangely, is not always understood: a military decision is sometimes treated as an “analytical conclusion.” It should be recalled that the question of choice (i.e., of decision, which is better) is very rarely resolved analytically, since it requires a human, non-formal understanding of political, military and scientific problems.
The next element of decision is mental completion of an action, i.e., simulation of an action. Simulation presumes a simplified description (mental in the given case), but simplification that retains the principal idea of the decision, such that its consequence can be evaluated. A model of an action should correspond to the willful act of decision, bringing it to fruition just as accurately as permitted by the mental capacity of man and required for the completion of a willful act, i.e., making of a decision.

Then we have consideration of the reasons for or against. When mentally tracing the course of events that may unfold as a result of a decision, i.e., modeling, these events must be evaluated. Evaluation requires apparatus and criteria; something is developed as a result of education and experience. Consequently willful interference is not presumed in the stage of analysis and evaluation. Comparison "pro" and "con" and the final choice is a different matter. Here again the volitional factor plays the leading role, since the number of these "pro" and "con" arguments may be very great, they may be combined in a variety of combinations, and there may be no distinct criteria for their importance.

Thus a decision is characterized by the volitional factor, dialectic realization of the relation of the goal and means, simulation, analysis and evaluation.

The preparation for and making of a decision require information concerning the situation and a formulated goal. We will construct a rough model by which a decision is prepared. Then we will discuss the model in detail. Figure 2 shows a model in the form of a diagram, which includes the following boxes: 1—reception, perception, selection, storage and display of information; 2—recognition of situation; 3—preparation of variants of decision; 4—evaluation of effectiveness of decision; 5—making of decision.

As seen by the figure, the model has direct flow and feedback.

Box 1 selects from incoming information and memorizes whatever might have a direct bearing on the decision. As new data arrive the memory is updated. The information stored in Box 1 is transmitted
partially or completely to the other boxes in convenient form. This is display of information. The task of box 1 is essentially to “compress” the input information, i.e., to reduce redundancy and transform it to the required form. This is done to eliminate information overload of the other boxes.

Box 2 performs the classification recognition task. On the basis of comparison a conclusion is made concerning correspondence of the situation to one of the patterns known by experience, or concerning whether or not the given situation is similar to several patterns, but does not correspond to any of them, or concerning whether the situation is an absolutely new one. In the latter case the basic attributes of the new situation are developed. Situation recognition is an important aspect of preparation of a decision, since it involves irreversible transformation of information. The recognition box is the last place where an error or misinformation can be eliminated, since the result of recognition is considered reliable. If an error is committed later, it cannot be corrected.

Box 3 works out the plan of decision on the basis of methods developed during the process of education and accumulation of experience. These methods may be typical, standard or new. The use of standard methods by no means presumes standard decisions. Under conditions of concentrated information and limited time it is impossible to get along without standard methods; the most important of them are presented in regulations, manuals and instructions. These methods are complemented by personal experience and experience of others. Each military commander works out his own original decision methods. At the same time the presence of typical, time tested methods makes it possible to free the thought process from search in a field that has no direct bearing on the specific situation and which could have been investigated earlier under peaceful conditions.

However, successful troop management requires more than the use of typical decision methods: new, original, one-time methods are required, which are products of creativity and inspiration. To lead the enemy into a blind alley, deliver a surprise attack, force the enemy to strike out blindly—all of these are recommended by the regulations and manuals, but nowhere is it stated (nor can it be stated) how to achieve this. New ideas may appear, but perhaps they may not appear. They may vary in originality and their fruitfulness requires checking. Meanwhile the importance of new ideas and new methods, which often are born in critical, and at first glance inescapable situations, is inestimable.

Box 4 evaluates the variations of a decision developed in Box 3. The memory of Box 4 stores the criterion and method of evaluation. The result is sent on in quantitative or qualitative form to Box 5.

Box 5 makes the decision. It is here that a willful act is performed. Since the decision inevitably contains an element of risk it is necessary to determine the tolerable risk and intolerable risk. In particular, a risk
is intolerable if the reliability of situation recognition is low. The risk is justified when a high effectiveness is expected and there is certainty in the correctness of situation evaluation.

The decision making process may be a one-time process, or it may be repeated and subjected to re-evaluation. The time required for decision making may vary: strategic decisions take years, but tactical decisions are made in a few seconds.

Let us turn to the problem of preparation and making of decisions. At the outset we will assume that the “man-machine” system is more perfect than “man” (people) or “machine” alone. Management automation is primarily a practical problem that must pass consecutively through various stages, from the simplest to the most complex and sophisticated. Far-reaching plans often are not completed for the simple reason that the principle of step by step development is replaced by the “all or nothing” principle. Times goes by, tasks and requirements change, and no useful result is attained. The initial ideas become obsolete and the project is terminated. In this book, therefore, we will proceed first of all from the need to distinctly formulate the purpose of each stage and evaluate the actual capabilities without losing sight of perspective.

This work makes extensive use of models. These are systems analysis models and their name derives from the fact that they represent the relation between input and output data in a schematic format convenient for analysis that solves a functional problem within a certain framework. These models, of course, are not construed to bear any morphological similarity to living organs or physiological similarity to vital processes, but they do have similar output parameters.

The purpose of this book is to aid in substantiating future prospects in the development of the theory and methods of decision making.

In the financial report of the CPSU Central Committee to the 24th Party Congress, comrade L. I. Brezhnev stated: “Perfection of the management system is not a one-time measure, but a dynamic process for solving problems posed by life.”

Decision making is one of the fundamental aspects of this problem. The authors gratefully acknowledge I. I. Anureyev, D. A. Volkogonov, V. M. Glushkov, Yu. M. Yermol’yev, G. G. Korshunov, P. G. Skachko and K. V. Tarakanov for their review and valuable comments.

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1 Materialy XXIV s’yezda KPSS (Materials of 24th Congress of the CPSU), Moscow, Politizdat, p. 66, 1971.
PART 1. METHOD

Chapter 1. Model of Thought

*Experience is higher than (theoretical) knowledge, since it not only has the advantage of generality, but also of immediate reality.*

*V. I. Lenin.*

1. Structure of the Model

There is no problem more profound, embracing and important in terms of its effect on progress, than that of thought. Many great scientists, politicians and military specialists have paid it its due. Analysis of "human" factors is rapidly becoming an exact science, and this is a "sign of the times." Nevertheless the phenomenon of human thought remains a deep secret.

It is known that the thinking process consists of several subprocesses; the goal and purpose of some of them have been subjects of conjecture. Some of the subprocesses, such as computation and assimilation of experience, have even been reproduced. This is still not enough. Successes have generated enthusiasm and sometimes unjustified hopes. Marxist-Leninist dialectics teaches us that it is impossible to penetrate into the essence of a phenomenon without examining it as a whole, by dissecting it into its component parts and trying to find the truth in each of them. Thinking is indivisible and continuous. To recognize thinking as a physical process is to know oneself. But it should not be forgotten that during the process of cognition the tool of cognition, namely thought itself, will be developed and improved, and consequently altered. Does this not mean "pursuit of self"?

"... Mankind faces a contradiction: on the one hand he faces a problem of comprehending in its totality the system of the world in its universe and, on the other hand, his own nature, like the nature of the world system, does not enable him ever to completely solve this problem. ... This contradiction ... is ... the chief lever of all mental progress and is resolved daily and continuously in the infinite progressive development of the human race..."¹

The problem has not only cognitive, but also applied significance. In particular, automation requires structural analysis of thinking and determination of fundamental laws. This requires a formal description of the functions performed by people and, on this basis, development during the process of infinite successive approximation of ever more exact and detailed functional models. Many general considerations have been propounded in the literature on the theory of creativity relative to thinking generally and creativity in particular. It is said that the human intellect is capable of "capturing an entire set of phenomena simultaneously," "in all interrelationships," "from different points of view," etc. There is a great amount of truth in all of this, but it sheds no light on the internal essence of thinking. Automation requires an effective model that, completely or partially, can be reproduced with the aid of the computer. On the one hand we need a model with maximum simplicity, and the other the proper reflection of the actual physical function of the process. Models that identically reflect the process itself at the required level of generalization are called optimal models. In an optimal model the external characteristics and the external connections of the basic blocks and of the model as a whole correspond to the external characteristics and relations of the simulated organs or systems.

We will attempt to construct a model in which each block is a "black box" with known external characteristics (they may be determined, though roughly, experimentally), but with unknown (at the time) internal structure. The model, of course, is not construed to bear the least morphological similarity to the human brain.

The model is illustrated in Figure 3. Intellect and thought are related to consciousness. We must first define the concepts that we will be using. Certain investigators are inclined to consider intellect and thought as an inseparable prerogative of man—Homo sapiens—and of him only. In this view any attempts to analyze the essence and elements of thinking are essentially eliminated from the examination. There is no doubt that there is much thinking of which only man is capable. But that is not the whole story. Without digressing into discussions on the definition of the term "thought" in this sense, and of its range of application in the universe, we should reject such a theory at the outset for structural considerations. It is barren and useless. The purpose of automation is to help man not only to act, but also to think, especially to make decisions. And without the assumption that the thought process can be reproduced to some extent, we are helpless. For this reason "intellect" and "thought" must be treated in a broader sense.

Abbot de Chardin, the great biologist and philosopher, who was ex-

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communicated from the church for his free thinking, and who died in exile, wrote that “human thought differs from animal thought in that an animal thinks without knowing it, while man thinks and knows it.”¹ This assertion holds a considerable amount of truth, which is very important: knowing that he thinks, man may control his thinking.

Figure 3. Model of thought. 1—consciousness; 2—subconsciousness; 3—nervous system of sensory organs; 4—memory; 5—system of connection between consciousness and subconsciousness.

Ashby, Kolmogorov and Glushkov state that intellect “is what insures choice one unit above random.” The following should be added to the statement; “in new, unexpected situations.”

The first element of the model of the thinking apparatus is **consciousness.** The information content of consciousness is quite large. In the opinion of certain researchers the rate of conscious processing of information is $10^{10} - 10^{12}$ bauds (binary units per second). This is not enough, however, to insure operational processing of all the information entering the human brain from the outside, from sensory organs, from internal organs and from memory.

The first “state” of consciousness is subconsciousness. We well know that all control of the organism, i.e. the cells, internal organs, involuntary actions (breathing, for example), reflexes and quick reactions, is exercised by the subconscious. This requires enormous information capacity. In order to react to the sudden change in the external situation (to a sudden attack, for example) and restructure several functions of the body, including internal secretion, in a fraction of a second, it is necessary to process up to $10^{14}$ bauds of information. According to certain data the information capacity of the subconscious is $10^{16}$ bauds, but even this figure is thought to be too low. The conscious is thought to function

more or less uniformly, and during the waking hours of a healthy human, fluctuations in the information load do not exceed 10 to 20%. The subconscious is loaded very irregularly: here, the peak load may exceed the average by thousands and tens of thousands of times. Consciousness is not engaged during sleep, but the subconscious is always awake. Consciousness processes information successively: it is very difficult to follow several objects and it is impossible to think simultaneously about several objects. The subconscious is compelled by "obligation to duty" to perform parallel processing of information: it simultaneously controls all organs of the body and many functions, evaluates the external situation and stimulates reactions of the body. This gives reason for assuming that many information models of the external situation from various sensory organs may be reflected simultaneously in subconsciousness. In addition, the same information model (situation) may be transformed variously, resulting in the appearance of several models of the situation (or assumptions as to its development). It is noteworthy that certain models may be formulated by consciousness, "examined" by internal vision or "heard" by internal hearing (the way we conceive imaginary events or melodies) and transmitted to the subconscious. All models henceforth may be treated simultaneously and compared. Parallel information processing affords the possibility of continuous transformation of information models and step by step change of the models for tests and evaluation.

In Figure 3 the subconscious is conveniently represented by the separate Box 2. From our standpoint the sensory organs may be also considered intellectual: they think and compute. The sensory organs are equipped with a sophisticated nervous system, which not only transmits information, but is capable of processing large quantities of information for evaluating a situation and controlling behavior. The eye of the frog reacts to moving objects and does not see still ones. Such selectivity is insured by processing of the entire mass of information reaching the eye. During analysis of patterns by the eye of the mammal much of the function of recognition is performed by the visual apparatus: detection of contrasts, distinction of contours, evaluation of geometric arrangement, evaluation of the topology of an object, etc.

The experiment described in ancient Indian books is indicative. In modern presentation it goes as follows: A pile of matches, which must be counted, is placed on a table.

The procedure requires some time. After several exercises the test subject notices that long before the completion of the count, he becomes aware of the sensation that he knows the number of matches, and a subsequent check indicates that he is right. The visual nervous system very rapidly completes the count. We are inclined to assume that what takes

1 Ramarcharaka, *Radzha-Ioga* [Rajah Yoga], SPB, 1911.
place here is not an evaluation on the basis of analogy with former observations (since no specific pattern is repeated), but rather a direct count.

The authors attempted to check certain capabilities in this regard and obtained the following results. A trained navigator evaluated “by sight” the speed of an airplane by plotting it on a map-table, with an error not exceeding 2 to 3%. The number of tanks was determined instantaneously and accurately on a map if it did not exceed 20. In either case the situation was quite complex. It turned out that it was comparatively easy to instantaneously evaluate the basic elements of a situation on a chess board: one move threats and mates. An increase in the time of observation beyond 1 to 2 seconds (up to 10 to 15 seconds) did not improve, but rather detracted from the result: the operator began to have doubts and made mistakes. Only when the time of observation was sufficient for cognitive calculation or analysis did the errors disappear.

Thus, the nervous system of the sensory organs (along with the controlling part of the brain) may be included in Box 3 of the model.

The fourth element of the model is memory (4) which stores all the information imparted at any time to man, and all the results of his processing, including all transformations of the initial models.

This is a thesaurus1 of the thought apparatus. The speed of conscious extracting of information from memory depends on the information productivity of consciousness and is comparatively low. The speed of subconscious extraction is much higher. Subconscious extraction may be accomplished in great masses of information concerning many objects simultaneously.

Everything that takes place in consciousness and subconsciousness is memorized, but for different lengths of time and with varying extraction times (apparently in different parts of memory). Information related to unconditioned reflexes is stored for life and is transmitted from generation to generation.

But the information related to a change in the functioning of various organs is apparently only partially memorized or is not memorized at all.

The examined model agrees in basic features with experience, but many important aspects are obscure. In particular, we have no idea what range of control consciousness has over subconsciousness; there are many disagreements among the scientists on this point. There are some facts (pertaining chiefly to the Indian culture) which indicate the enormous capabilities of stimulation or suppression of subconsciousness—to the point of controlling the operation of internal organs. Unfortunately, however, science has not checked and systematized data on these questions. Therefore the interaction between consciousness and subconsciousness must be regarded as yet another “black box” (Box 5) without attempting to pry into its essence.

1 Literally: treasure (from the Greek).
In Figure 3 the connections between the boxes of the model are shown as smooth and distributed. This is done to stress the absence of sharp boundaries between functions (and accordingly between boxes), since it is impossible to establish where consciousness ends and subconsciousness begins, where the nervous system of the sensory organs ends and the brain itself begins.

An important element is omitted from the model: the center of emotions. We shall return to the question of the influence of emotions on behavior.

We will try to explain by way of a simple example how the model operates. Man performs a complex assignment associated with danger. Knowing about this ahead of time, he consciously works out the indications of danger, which are stored in his memory; his sensory organs and sharpened. All the information is immediately analyzed in Box 1 primarily from the standpoint of the indications. Man knows how he should proceed in one case or another. To achieve his goal, through will power he forces himself to act as he is supposed to act (i.e. in accordance with the idea with which he identifies), regardless of the risk. Here he must suppress conscious and subconscious impulses. If similar assignments must be performed quite frequently, conditioning to danger occurs, the sense of fear weakens, the need for will power fades, consciousness is liberated from control, and behavioral control is transferred to the subconscious: the correct action is performed by the reflex.

Consider another case: A person is calm, stable and engaged in thoughts of abstract subjects. Suddenly he is subjected to danger. The sense of danger occurs earlier than information about the danger reaches consciousness: the nervous system of the sensory organs (Box 3) and the subconscious (Box 2) are both actuated. Their reaction may occur instantly and produce active defensive action, even though it is sometimes a false alarm.

In such cases subconsciousness and consciousness often conflict, with the result that a mentally unstable state of “stress” and panic occurs.

Thus we will assume that the model is accurate within the framework of the stated problem. We will perform thought experiments with it. We will be interested in various aspects of dialectic thought, which we will now examine.

2. Empirical Thought

There are simple situations in which man may become oriented and act according to ready-made patterns. This means that during a process only two boxes will operate: memory (Box 4) and one of the first three. The observed situation is identified with one of those stored in the memory of subconsciousness or consciousness; a stereotypical reaction is selected and realized.
This is empirical thinking: the accumulation, systematization and organization of experience. After making a decision in a specific situation man compares it with his own experience, recognizes and selects the method of action which brought him success in the past. This is the earliest and most primitive method in the history of evolution. Animals are also capable of learning from experience; this occurs in the lower animals through sampling of conditioned reflexes, which may be changed into unconditional reflexes and acquire a hereditary character. The very first object which a chick sees on emerging from the egg, which is imprinted upon its memory, becomes the object of its long term attachment—usually the hen, but it may turn out to be a football or a pine cone. Such a capability is developed by hereditary experience and is essential for survival. The more developed the brain of an animal, the more capable it is of genuine learning and acquisition of personal experience, i.e. certain time-tested ways of behavior. Man learns a part of social experience and also acquires personal experience.

Mathematics at a certain stage of development was based on empirical thought. The ancient mathematicians constructed their science as a set of rules and had little concern for establishing the causal relationships between them. The rules were checked experimentally. Analogous situations also existed in other sciences.

Approbation and evaluation of experience take place with the active participation of consciousness. Experience is eventually assimilated and may be transformed into a reflex, into subconsciousness. Then the process of situation evaluation, choice of method of behavior and its realization will proceed very rapidly, practically instantaneously. The soldier in Suvorov's army spent much time mastering methods of hand-to-hand combat and reducing them to automatic behavior; after all, the experience of a peasant serf was far from that of a military man. At the same time he developed a capacity for quickly orienting himself in a situation and choosing the best course of action: "every soldier must know his maneuver." His lack of familiarity with the problems and actions required the participation of the mind in training: Suvorov was opposed to meaningless drill. But after the methods were mastered, their applications did not require mental power. Formation commands are first assimilated consciously, and then automatism takes over (even though spoken information is received consciously).

The same is true in the forms of more complex functions and commands. When flying an airplane most operations are done automatically. In spite of the sudden change in the situation, the experienced pilot can evaluate it and react, and consciousness participates only partially in this process, i.e. intermittently. But aviators know how much hard work,

1The ideal solution in terms of simplicity and effectiveness in the interest of the species. Any other solution (for example, orientation toward warmth and safety) would not have worked from the information standpoint.
colossal mental stress and willpower such automatism costs. Very quick and correct reactions can be achieved through well thought out and organized training programs. The subconscious observation centers of the good scout operate so precisely that it is almost impossible to surprise him: he can spot a surprise attack if, of course, the attacker does not have better skills. But once again this is gained through serious preliminary mental work and willpower on the organization of subconscious activity. An analogous situation is encountered in tactical warfare. The rules for conducting combat were verified by experience, so that empirical thinking is used even in control of military formations.

The main disadvantage of empirical thinking is that it is limited. During the process of development the mutual relations between groups of people became more complex and the relations between people and nature began to diversify. This led to an increase in the number of new unexpected atypical situations in which orientation simply on the basis of experience became impossible. The specific weight of mixed situations, which also readily extend beyond the framework of past experience, increased.

Let us assume that there are three situations: A, B and C. Each of them corresponds to optimal behavior \( a \), \( b \) and \( c \). Suppose mixed situation \( AB \) arose, i.e. a situation that includes both A and B. What actions should be taken? It need hardly be proved that behavior \( ab \) may be less than optimal and also impossible, for example, if actions \( a \) and \( b \) are incompatible. If the number of possible primary situations is equal to three, then the number of mixed situations is four: AB, BC, AC and ABC, and the total number of possible situations is seven. Consequently the behavior based on experience will be optimal in only about 50% of the situations. But if the number of primary situations is 10, then the total number of situations exceeds 100 and the optimal behavior is guaranteed in less than 2% of the situations (i.e. for the initial simplest situations) assuming that they were correctly recognized. We see that as the situation becomes more complicated the capabilities of empirical thinking diminish rapidly. Nevertheless the specific weight of empirical thinking is great, since the simplest “primary” situations are encountered most often (in day-to-day life they probably comprise about 99.9% of all possible situations). Therefore it may be affirmed that the behavior of an individual man is insured in the vast majority of cases by empirical thought, to which all vital and working functions are related.

There was the case of one French naturalist—an entomologist, lost in a South American jungle when he became separated from his expedition, and who lived in isolation for about 30 years. During this time he forgot how to talk, lost his memory and essentially his consciousness in the general sense of the word. Nevertheless he survived, gathered food, had no weapons; in short, fought for his life and, most interesting, continued to assemble his collections. The situation required the making of difficult
decisions, and the man finding himself, by force of circumstance, in absolutely strange conditions, gradually developed dynamic stereotypes that enabled him to exist at the level of subconsciousness. When the scientist was returned to civilization he was able to restore his consciousness and part of his memory, but he remembered nothing about his solitary life.

Thus, empirical thought participates only in the development of simple rules of behavior and methods of assimilating them. Actions themselves as a reaction to a situation are accomplished so quickly and automatically that consciousness does not take part in them. Therein consists automatism, which officers, noncommissioned officers and enlisted men must possess in order to perform typical operations: to accelerate their performance and to liberate consciousness for more important tasks. Empirical thinking essentially provides the possibility of mastering any weapon on the level of technology. This is quite well illustrated by the history of military science. A sword duel required the mastery of several dozen moves, and speed, skill and physical stamina were of vital importance. The ability to choose the most effective drills and to secure the conditions necessary for their use in battle comprised the heart of individual combat training.

In the bloody war between the Conquistadors and the Aztecs the difference in the quality of the weapons on either side and in knowing how to use them could not have been a decisive factor, if only because the natives were far superior in number. Without touching upon the political and religious aspects of the fall of the Aztecs, it may be said that the Aztecs lost many battles because of their poor mastery of tactics in group and mass warfare. The use of cold steel in ancient battles inevitably led the mass battle to a set of duels, in each one of which empirism, i.e. the knowledge of stereotyped moves, skill and endurance decided the outcome. However, the general success in battle was determined largely by the initial disposition and organization of the battle, which required considerably more on the part of the commander than the knowledge of past patterns. As the quantitative makeup of the armies increased, therefore, the empirical approach to troop control was abandoned. The larger a formation, the less the specific weight of empiricism.

Let us return to our model. It is capable of reproducing those aspects of empirical thought which were described above. Here the order of operations—in building models for standard forms of behavior, skills and habits—should be determined on the basis of experiment.

Empirical thought is clearly inadequate for the competent utilization of weapons, and especially for the management of groups and masses of people.
3. Axiomatic Thought

The second method of thought is axiomatic, thought by rules. The essence of axiomatic thought consists in a formation of some system of general positions and principles, elevated to the status of "self-evident truths", and also a method of deriving from them specific decisions, instructions and rules.

Axioms are concentrated expressions of social experience and are held to be true in each individual case. Axioms are applied to a specific situation, and a conclusion is drawn. Axiomatic thought requires analysis of a situation and therefore it is sometimes also called analytical thought. It is noteworthy that the mathematical term "axiom" is rarely used in military science, but the meaning is the same: we are discussing the initial positions, considered beforehand to be valid.

The elements of axiomatic thinking were inherent to man in prehistoric times, although the principles of axiomatic thinking as they exist today were formulated and adopted by the ancient Greeks, which enabled them to rise intellectually above their contemporaries and to lay the foundation for the modern scientific method. Euclid formulated five axioms and on the basis of them built the foundation of geometry. One of Euclid's achievements in geometry was the discovery of the feasibility and method of deducing the specific from the general. Axiomatic thought, in all probability, historically made its appearance earlier in military science (and in other applied sciences) than in mathematics: the level of abstraction is too high in mathematics, and the formulation of axioms and the development the tools for arriving at conclusions required incomparably more rigorous and far reaching generalization than in other sciences. The foundation for such generalizations was built out of empirical results, and therefore naturally, axiomatic thinking appeared later than empirical thinking.

Axiomatic thought is essential to the development of science, technology and art; it comprises the intellectual conscious foundation of human activity. It is also essential for development of military science. The generals of the past contributed much, both in axiomatics and in the method of construction of conclusions. Surorov's *Nauka Pobezhdat'* [The Science of Winning], in a unique form, expounds on what was then the most advanced principles of warfare. "Bystrota i Natisk" [Swiftness and Charge], "Kazhdyy Soldat Dolzhen Znat' Svoy Manevr" [Each Soldier Must Know His Maneuver] was not simply wishful thinking, but a conception, which the great general tried to instill in commanders of all ranks. The "Bystrota i Natisk" principle hardly retains its former meaning and force under conditions of nuclear missile warfare.

Military "axioms", of course, do not have self-contained powers. We use this term here only because it correctly reflects its use. But the basic principle of mathematical axiomatics—derivation of a specific de-
duction based on general theses, and applicable to specific conditions—remains in force. And the content of the terms “axiom” and “conclusion” is not entirely the same as in mathematics. The military “axiom” is not an eternal, immutable, formal truth, but a guide to action. Military “axioms” are changed, discarded, and new ones appear.

The great specific weight of axiomatic thinking in military affairs, in comparison with empirical thinking, is a very important fact. This is manifested in the organization of specific combat actions on any level. Axiomatic thought immeasurably expanded the range of conditions under which a commander could effectively act.

In principle axiomatic thought should be primarily defined as strictly logical thought. A specific action must be the inevitable logical consequence of axioms, which in turn rest on the characteristics of a concrete situation. Determinism, absolute correspondence of cause and effect, lead to uniqueness. The effectiveness of the result and its practical worth should depend only on the validity of the axioms and on the correctness of the recognition of the situation (this question also has its own axiomatic aspect). If the axioms are correct, the situation is known and the tools for reaching a conclusion are sufficient, then there should be no erroneous conclusion.

In actual practice, some of the initial premises (about the enemy, for example) are not reliable.

The tools with which a conclusion is reached include not only mathematics (mathematical logic in particular), but also other means, which will be discussed later. This makes an impression not only on the process by which a conclusion is reached, but also on its essence. The uniqueness and correctness are unconditionally valid in typical cases, but not in all of them.

New, atypical situations that do not correspond to previous experience may arise in military science. Therefore a rigorous conclusion may turn out to be wrong. In such situations mathematicians alter the axioms by taking into consideration the new experience. In military matters it is necessary to act in an unexpected situation until new axioms can be formulated. Axiomatic thinking is useless in this case.

One of the tenets of Napoleonic tactics was the use of mass artillery fire against infantry forces. Having received experience as a junior artillery officer, Bonaparte successfully used artillery in Toulon and from that time on, used this favorite idea of his without change. Bonaparte’s “artillery forward” made history. The given axiom may be expressed in the most primitive form as follows: if artillery is available and if the enemy attacks or defends itself with tight military formations, artillery should be used as the chief means of warfare against infantry forces. On this basis were developed empirical methods, which were used successfully in specific battles. Depending on the situation, a conclusion was drawn concerning the most effective placement of artillery positions, methods of conducting fire, etc.
Napoleon, of course, as with other tenets of his strategy and tactics, could not keep the primacy of artillery a secret, nor did he try. It wasn't that Napoleon's enemies didn't understand these tenets (they were sufficiently qualified), but they had their own axiomatics they did not give sufficient weight to his tenets and they kept losing. The first time that Napoleon's tactic did not prove its value was in engagements with the Russian army.

The advantage of axiomatic thought is that it provides scientific foresight within the limits of assumptions made. It gives an objective evaluation of the actual ratio between forces, the validity of assumptions concerning the development of events—if they will develop according to the same rules as before; a quantitative analysis of the situation, a determination of "bottle necks" in our disposition and in the disposition of the enemy.

If the significance of empiricism decreases as the organizational level becomes higher, then the value of logical conclusions, conversely, increases. Also, as the organizational level becomes higher, the significance of precision of situation evaluation increases, and the chief advantage of empiricism—the swiftness of reaction—is lost. On the other hand, the larger the number of troops, the more valid the general principles: statistical laws come into play. It should also be pointed out that the diversity of situations becomes smaller (in a short historical time span, of course) as the area and time they occupy become greater. The combined effect of various events, but related by general principles, results in the leveling off and an increase in the specific weight of typical situations. Analysis of such situations may be carried out to a considerable extent ahead of time, which expands the range of axiomatic thought.

One of the disadvantages of axiomatic thought, particularly in military science, is its incompleteness. Armed warfare is primarily a social phenomenon, and social processes are too complex to be embraced by any group of axioms. Therefore the basic idea of the uniqueness of a possible conclusion, even under favorable conditions, is by no means always valid. Some general logical outline is involved in the derivation of a conclusion. The positions reflected in the instructions, directives and orders, in traditions and experience of the troops, permits the construction of this outline. But political, social, emotional, psychological, technological and organizational factors cannot be taken into account completely. Therefore the determination of the principles of organization and conduct of warfare and battle is complex, even agonizing; as a rule it lags to a greater or lesser extent behind the requirements of life.

Axiomatic thinking is too formal for military matters. It essentially does not permit the working out of an unexpected solution. Axiomatic thought is available to the same degree to both conflicting sides, and therefore each side can think like the enemy and predict his actions. The result is that everything is known beforehand.
Axiomatic thought yields poor results in a situation that does not fit into the axiomatics. In this case the entire logic construction may be wrong.

Let us see how the model in Figure 3 reflects axiomatic thought. The center of thought, built on rigorous laws of logic, may be only consciousness (Box 1). All the information about axioms and situations is concentrated in the memory (Box 4). All processing of information takes place in Box 1, and the result is fed to the outside world and to the memory. Subconsciousness does not take part in axiomatic thought.

Empirical and axiomatic thought are included in both dialectic and metaphysical thought; we shall not discuss the latter.

4. Dialectic Thought

Dialectic thought is the basis of progress.

Dialectic laws are laws of nature. Along with the physical laws of conservation, they reflect in the most general form all processes that take place in the universe. Thought obeys the laws of dialectics. Both empirical and axiomatic thought reflect real phenomena and contain elements of dialectics. These elements, however, are not the determining factors. Any exact science, primarily mathematics, is dialectic, but at the same time mathematics is constructed formally, axiomatically. In the case at hand we are discussing the use of dialectics for constructing judgements and deductions. One of the facets of the essence of dialectic thought consists in the detection and surmounting (and sometimes utilization) of a basic contradiction of a situation in the interest of discovering the truth or obtaining a goal. Einstein asserted that discovery is not a matter for logical thought, even if the final product is related to a logical form.

Development of a situation is possible only in the presence of contradictions. The absence of contradictions signifies a stagnation period. The detection and disclosure of contradictions is the discovery of the causes that give rise to development. To overcome and to use contradictions means to aim development in the desired direction. Empiricism and axiomaticism are based on past experience; dialecticism is based not so much on experience as on the essence of a specific situation. Axiomatic thought is continuous, but dialectic thought includes qualitative jumps. The discovery of contradictions by the logical approach is sometimes possible. Quite often the contradiction is disclosed when a new empirical fact is encountered. A contradiction can be overcome only with the aid of dialectics.

The characteristic formal quality of dialectic thought is a threshold transition, a qualitative jump in reaching a certain level.

Man often uses dialectic thought unconsciously. This is particularly characteristic of inventors. The creative successes of mankind are inalterably related to dialectic thought. Each step in the development of civilization, each step in mastering the forces of nature, each scientific
discovery and invention are consequences of a dialectic jump. Empirical and axiomatic thought cannot create anything fundamentally new, since they are nothing more than the rational application of old, previously accumulated knowledge. True, a new fact may be discovered empirically. It is possible on the basis of a formal conclusion to arrive at the statement of a new experiment, and then to conduct the experiment and obtain new data. This has happened both in science and in the military. But a fact must be thought out, connected to real life, and its place determined. Mental experiment, a model of possible events, precedes a physical or social experiment. First an assumption is made about the possible outcome or result. In conducting a mental experiment we must construct an assumption as to how it will proceed. Where does such an assumption come from? There is insufficient knowledge: if the knowledge were there the experiment would not be necessary. Logic is of no assistance: it is based on old data.

Assumption, conjecture and guess work are the result of thinking out facts in their entirety, in their interrelationships, and of the construction of remote analogies. This is dialectic thought. Evaluation of phenomena from the standpoint of their development and relation may also take place subconsciously. But in order that the processes take place in the subconsciousness in the corresponding fashion preliminary dialectic mental work, “organization” of the subconscious, is required. A creative process is related primarily to dialectic thought. In day-to-day life there are not so many critical instances that require the resolution of complex contradictions. This is very important, since conscious dialectic thought requires enormous internal mobilization and the marshalling of all intellectual forces; most people are not capable of continuously using it in daily life. Indeed, it is not necessary to use axiomatic thought as often as empirical thought.

Dialectic thought has no boundaries. Nature, including the nature of social phenomena, is inexhaustible. The richer the intellect, the more deeply it can penetrate into the essence of phenomena but no one can completely exhaust it. The level of dialectic thought, like the level of creative capacities, varies from person to person.

The discovery of the periodic table of elements, the theory of relativity, and thermonuclear reactions were epic events, which were possible through the use of dialectic thought, and related to the discovery of contradictions in the understanding of the laws of nature and overcoming of these contradictions through the development of new conceptions. In the case at hand we are discussing fundamental scientific achievements, obtained only through genius. But even problems on an infinitely smaller scale may turn out to be unresolvable axiomatically or empirically, if there is something in their essence that extends beyond the range of experience. The most characteristic feature of dialectic thought is the possibility of obtaining a correct result even though there is insuffi-
cient information. This seems to be ridiculous at first glance: indeed, we say that it is impossible to develop information about the surrounding world using internal means only. This is true: new information, reflecting the objective world, the environment, cannot be developed. But conjectural information about the environment can be developed. The extent to which it will be accurate requires checking. New ideas may not correspond to generally accepted axioms. Therefore they are very difficult to assimilate and they travel an agonizing road to acceptance. Re-phrasing Niels Bohr's famous expression, it can be said that an assumption must be ridiculous enough in order to be true. Still, it is much easier to check an assumption than it is to develop it. The power of dialectic thinking consists in the fact that it permits the development of an assumption. The final criterion of truth is practice, experimental verification. Uniqueness is not a property of dialectic thought: quite the contrary. A correct, fruitful idea is gained at the cost of many mistakes.

Unfortunately we still know very little about the functioning of the brain and the mechanisms of thought. Therefore we cannot accurately picture how all this takes place. In particular, mathematics does not have the tools that could be used in dialectic thought, for example, the ways that analysis and logic are used in axiomatic thought. True, metamathematics (the science of mathematics), dialectic logic and mathematical modeling have undergone considerable development in recent times. Time will tell how fruitful the application of new achievements in practice will be.

By their nature, class struggle and armed struggle to a greater extent than other realms of activity require the dialectic approach. Contradictions* between the conflicting sides are sharp, and the responsibility for decisions is tremendous in view of the serious consequences due to errors.

We will attempt to determine more specifically the range of application of dialectic thought. We must first determine the basic contradiction of a situation. In military matters there are many contradictions and the first of them is the endeavor to inflict damage on the enemy with minimum losses. But this contradiction is too general to be used constructively. It is necessary to find the main contradiction determining the given specific situation and expressing its internal, unique essence and specificity in terms of the stated military objective.

We begin with a simple example. One of the dialectic contradictions of the world around us is the fact that it is simultaneously continuous and noncontinuous (discrete). This is one of the tenets of Marxist philosophy. In the military an analogous contradiction is encountered every time: it is necessary to hold (in defense) an extended front, knowing beforehand that the enemy will attack in one or several comparatively

* While the basic meaning of the Russian word protivorechie is contradiction, there are also the connotations of incompatibility (e.g. incompatible situation), opposition or conflict (e.g. of ideas), and of something being mutually exclusive.
narrow places, but where it is not known. The opposite situation is encountered in an assault. The contradiction between the presumed continuity of the range in which military actions are possible and its actual discontinuity—concentration of objectives and forces, i.e., the contradiction between continuity and discreteness in a given space—is a general property of military situations and is used very frequently.

An analogous contradiction exists between the continuity and discreteness of military actions in time. This contradiction was used successfully by Suvorov: the sudden and unexpected advances for which the great general tenaciously and steadfastly prepared the Russian army for many years, enabled him to be where and when he was least expected by the enemy. These contradictions may acquire a variety of forms in specific situations.

The contradictions that are characteristic of military situations may be divided into several groups. Information contradictions comprise a large group of contradictions. The basic contradiction is the one between the need for complete knowledge of a situation for arriving at the best decision and the absence of this knowledge. Less general information contradictions may play the decisive role in specific situations. Such, for example, are the contradictions between the need to consider all features of a situation when preparing the decision and the limited capabilities for processing the information; between the information at the commander’s disposal before reconnaissance and reconnaissance information; between the endeavor to misinform the enemy and the need to conceal his own means of misinformation; between the endeavor to strike at the enemy and to conceal the deployment of his own firing positions; between concealment and limited time available for preparing military actions, and so on.

No less important are the contradictions in the distribution of resources. Suppose the commander has a firepower capability that cannot be replenished. An increase in the consumption of ammunition at each stage of battle increases the losses inflicted upon the enemy, but it also decreases the reserves that may be needed in the future. An analogous contradiction occurs in the distribution of forces. For example, an increase in the training time of new troops during the time of war increases their fighting capability, but this always involves reduction of replacements. Bringing supplies, arsenals and repair facilities closer to the front increases their operational capabilities, but also increases their vulnerability.

Contradictions related to conditions of military actions are very important. Routes that are hard to travel fatigue the troops, but on the other hand they are often the shortest and invulnerable to the enemy. Night actions are extremely difficult for the attacking side, but on the other hand great damage can be inflicted upon the enemy. The capture
of a fortified region generally involves great losses, but it seriously weakens the enemy. Attacking the enemy at the rear can cause him to panic and result in his defeat, but it is dangerous to the attacking troops, who may become surrounded. The concentration of forces increases the chances of accomplishing a mission when breakthrough occurs, but it also increases losses in the event that the enemy attacks a concentrated grouping.

Social and moral-political contradictions, characteristic of the capitalist armies, are extremely important. Class, group and religious contradictions, contradictions between personal interests and missions, between social ideals and practical action, etc., comprise the antagonistic aspects of the armies of the capitalist countries and pervades them from top to bottom.

One should also bear in mind the psychological contradictions that occur and are manifested in each individual and in groups of people. Social psychology plays a tremendous part in the military, and it is very important to take into consideration. In this regard there are many contradictory aspects which are not very well known. Contradictions between the survival instinct and service (social) duty, between carrying out orders and initiative, between responsibility and self-assertion, between valor and discretion have often manifested themselves in combat and have given rise to serious events.

Contradictions should be considered possible between heterogeneous factors which in this case form a dialectic unity and determine the situation.

An interesting example of this type is found in the memoirs of Marshal of the Soviet Union, K. K. Rokossovski. Before the war a foxhole defense system was recommended, in which the infantry suffers fewer losses from enemy fire. However, the minimum loss factor was in conflict with the psychological factor of "fear of isolation." Here is what K. K. Rokossovski wrote: "As an old soldier I have taken part in many battles, and that I felt very uneasy in this nest is a fact that I frankly admit. The urge to run out and see whether my comrades were sitting in their nests or already were gone, and I was alone, never left me. If the sense of fear never left me, what must it have been like for the man who, perhaps, was in battle for the first time!" This contradiction was resolved by the introduction of trench warfare, and this turned out to be an effective and long term measure.

One might ask whether there is any nondialectic method of resolving contradictions. This is an important question, since one of the features of dialectic thought is that it does not always "work." Therein, incidentally, lies yet another dialectic contradiction. The axiomatic approach

to overcoming contradictions consists in the most advantageous compromise, in the partial reconciliation of contradictions. The axiomatic approach offers nothing qualitatively new, but on the other hand it enables us to find the "golden mean." For this purpose the potent mathematical tool of optimization was developed, which affords specific formulation of a problem and its accurate solution.

Suppose it is required to determine the width of the breakthrough zone of a uniformly fortified front line. By narrowing the breakthrough zone we insure a higher density of fire, manpower and equipment, and consequently alleviate the problem. But at the same time the entry of a large mass of troops into the break is complicated, their supply is hampered, the effectiveness of the enemy’s artillery and air strikes is increased, and there is the increasing danger that the penetrating forces will be isolated and surrounded, etc. By widening the breakthrough zone we diffuse the forces and suffer heavy losses in the most important stage of the operation. It is obvious that neither excessive concentration nor dispersal of forces along the entire line can bring success: some intermediate solution is required. To find it we may calculate the effectiveness of combat actions for several penetration zone widths and select the best version. This approach is sometimes taken, but the use of special mathematical methods produces the best results. Any calculation requires a description of the problem and the making of certain assumptions relative to the actions of our own troops and those of the enemy; herein lies axiomatics, which in this case acts only within the limits of the problem. A deficiency in the solution derives from the essence of axiomatic thought: the dialectic contradiction is not resolved, but rather reconciled. This may lead to success under certain conditions, but this success is derived from compromise and is limited to the potentialities of compromise. On the other hand, this is a reliable method and is based on exact quantitative calculations. It can be relied upon only if forces are sufficient and the enemy is guided by logic alone. But if the enemy can counteract logic with dialectics (indeed this situation contains dialectic contradictions which may be useful to the enemy), then axiomatic logic may turn out to be the wrong approach.

Therefore the real battle of minds is the dialectic battle. An example of dialectic thought is the decision of Marshal of the Soviet Union, G. K. Zhukov to embark on a night advance using antiaircraft searchlights to take Berlin during the Great Patriotic War. Unexpected actions are easier to carry out in darkness, but the advance on a heavily fortified area in an alien territory is extremely complex. Herein lies a dialectic contradiction typical of the given situation, and which was formerly resolved by compromise: either accept the risk of attack in darkness, or choose another time. The antiaircraft searchlights of that day had a rather long range (9–10km) and played an important role in air defense. The largest
formation of antiaircraft searchlights was a regiment with 12 to 16 searchlights, that were practically never used in support of nighttime combat operations of ground forces: a searchlight was not easy to set up near the front line, and was comparatively easy to shoot out. The dialectic contradiction here was between the usefulness of high light output and the disadvantage of vulnerability.

The combat ranks of the attacking forces had 140 searchlights concentrated every 200 meters, lighting up the positions and fortifications of the enemy and blinding him. It was practically impossible to knock out such a number of lights under conditions of counter-artillery attack of unprecedented might. The large scale use of searchlights for ground operations under these conditions transformed the quantitative factor into a qualitative one: the effectiveness of searchlights increased with a sharp reduction of vulnerability. Such was the manner in which one contradiction was resolved. This made it possible to resolve a second contradiction—between the advantage and complexity of night-time combat operations: the problems of the enemy increased and our problems were significantly alleviated. The unusual combination of weapons, formerly used in a different manner, offered a qualitative leap in weaponry without any use of new technology. As a result an absolutely new situation arose, about which the enemy had no knowledge. The psychological effect of this offensive operation was so great that many experienced enemy officers and soldiers lost their powers of reason. The idea that gave rise to the given situation was a consequence of dialectic thought. This was the result of military creativity.

We will attempt to set forth several considerations relative to dialectic thought, proceeding from the model described above.

5. Model of Inspiration

Inspiration is capable of producing an unusual flight of thought. "And into my mind burst a flash from the heavens, carrying the truth of all its powers"—thus wrote Dante.¹

We will try to depict the mechanism of a creative leap and construct a model of it.

The most surprising property of dialectics is that it affords an escape from customary notions. At the same time these notions are its foundation, its material base. No inventor can describe the bright drawing of a new idea more convincingly than with the aid of the exclamation: "Eureka!" but it all boils down to one thing: hard mental work precedes insight. According to Tchaikovsky, "Inspiration is a guest who does not like to visit the lazy." In this regard, rephrasing the famous Oriental saying, it may be added that creativity (especially military creativity) is

¹ *Ray,* Pesn' XXXIII [Paradise, Canticle 33].
“a road, which for thousands of years has carried either the dead, or the weeping, or the creative human heart.”

If we approach problems for which creative solutions have been found, from the pure information standpoint, then what stands out first of all is the enormous discrepancy between the quantity of information required for detailed descriptions of the problem, and the information with which the human brain can consciously work. Evaluation of certain situations has shown that the deficiency in the “capacity” of the conscious mind approaches six orders of magnitude (i.e. a million times less information is processed than required), and even assuming that the error in the evaluation may be 2 to 3 orders, the discrepancy is still startling. The assumption, quite often stated in the literature, to the effect that man “processes information selectively”, is blasé and unconvincing. Information does not disappear and cannot simply be “thrown away”: before it can be discarded it must be processed. If one is not to depart from materialistic positions, one must assume that all the information arriving in the human brain, directly or indirectly concerning a problem, is processed. And if such processing cannot be accomplished consciously, then it must take place subconsciously. In terms of capacity the conscious sphere of our brain is a tiny island in the boundless sea of the subconscious, the true capacities of which we are still unable to evaluate. Nevertheless the role of consciousness is tremendous: It organizes, directs, analyzes and, to some extent, controls the subconscious activity of the brain and forces us to act orderly and purposefully.

We can only guess how the conscious and subconscious elements interact with each other during the process of dialectic thought. Nevertheless the development of an approximate simple model of such interaction is possible. When we examine a tree, covered with leaves, trying to understand what this is, the subconscious performs a great task. The eyes perceive information about the tree, transmitted by light rays—around 100 million binary units. It is impossible to conceive of this flow of information: it is too great. Nevertheless the processing of information for the purpose of recognizing a “tree with leaves” occurs in a split second. Consciousness takes over in the last stage, when a decision is made: “tree”, “shrub” or “house” and the result is perceived in final form. “Primary” processing of information takes place at a very high speed, of which consciousness is incapable. There are two streams of information: one from outside and the other from the depths of memory. Specialists are of the opinion that the construction of a visual pattern is a battle with illusions. “To unravel” what we see means to construct several verisimilar assumptions and compare them with the incoming information. Comparison may be done by two methods: The assumption (generalized pattern) may be transformed into primary information (visual pattern) and compared with what the eye sees; or,
the result of observation (processing of information) may be compared with the various generalized patterns stored in memory. The latter method is inferior: it does not permit attention to be concentrated on small, but important details that characterize a given assumption. Therefore, for examining an object (already knowing what it is), the latter method is suitable, but in order to guess (using hard-to-see details), the former approach must be employed.

In the first method an information model of conjecture is formed in the subconscious: it is compared with the object being observed. Consciousness gives instruction, impetus, and direction, determining the range of search, the idea, and purpose. Or, to say it in a better way, the range of interest of whomever is looking at the tree: if a person is a scout, he is looking for the enemy, but if he is a hunter he is looking for the tracks of his prey. The instruction to search is given in generalized form, applicable to the classification and categories with which the subject thinks. Subconsciousness forms a set of models—some of them real, occurring on the basis of remote associations, extracted from a completely different field, and some of them complete fantasy—a comparison is made and, in accordance with certain criteria (established by past experience) forwards the result to consciousness, where final analysis and selection take place. The element of randomness, of a lucky guess, is also important. However, the range of random search is limited by conscious preparation. Sometimes consciousness plays a conservative role, suppressing fantasy by shortening a search or discarding barely formulated or simply sketchy models.

A succession of guesses passes before the mental gaze, and we are not always able to single out the one that best corresponds to experience. We have other information about the resemblance between the guess and the object. This information is based on experience, on such fine, unique, and sometimes disconnected details, which in themselves are insufficient for generalization, that the consciousness is not aware of these details and cannot actively work with them. Such information is stored in the subconscious and comprises the foundation of intuition. A dialectic experiment is carried out, not on a real object (situation), but rather on a mental model. In view of the tremendous information content of the subconscious such experiment takes place at great speed—"with the speed of thought." The initial model may be altered in any desired way for the purpose of constructing a new model that exhibits new properties. The experiment may include replacement of parts of the model by new models that have no bearing at all on the initial model and are not even remotely related to it. This experiment is to some extent random and to some extent purposeful, but the path of the experiment is determined by the consciousness for the purpose of arriving at a model with defined properties. Both consciousness and subconsciousness can operate only with models or parts of models which are trans-
mitted from the sensory organs or stored in memory, i.e. they are a reflection of sensory perception.

The transformation of the models may be both continuous and discrete, i.e. intermittent. In particular it can be imagined that two models are initially constructed—the initial (actual) and final (desired), and all the intermediate stages, i.e. the connecting link between them, are constructed on the basis of trial and error. There may be several times more erroneous variations of the model than of successful ones. Thus, the mental evolution of the initial model, including its qualitative alterations (jumps) is the basic means of dialectic thought. The interaction between consciousness and subconsciousness may be described, if not very accurately, then at least graphically, by Taine in his book *Ob uime* [On Intelligence]. This description is deserving of discussion. “Human judgement may be compared with a theatrical stage of undefined dimensions, whose footlights are very narrow, but the stage spreads out from the footlights. In front of the lighted footlights is room for only one actor. Then, on various parts of the stage, are different groups, which are less and less distinct, the farther they are from the footlights. Even more distant from these groups, in the wings and far back stage, is a collection of dark forms, which sometimes make a sudden entry onto the stage, even up to the footlights. This anthill of actors of all sorts is always in some sort of motion and spotlights leading “stars,” who alternately appear before us as if in a magic lantern.” Taine like other investigators, especially mathematicians, distinguishes consciousness—“as a place in front of the footlight,” subconsciousness—“back stage” and the intermediate region—“the stage” (another term, “fringe consciousness,” is used in the literature).¹

Zh. Adamar² distinguishes four stages of creativity: preparation—incubation—inspiration (Russ. word is “dawning”)—completion. Inspiration is an intuitive factor, based on a set of subconscious processes that results in synthesis.

To believe or not to believe intuition is a question that is answered consciously. But not always: sometimes unexplained (from the standpoint of consciousness) steps are taken. Front line troops are well aware of cases when a man, acting illogically for reasons unknown to him, moved from a less dangerous place to a more dangerous one and remained alive, while one who stayed in seemingly a safe place perished.

M. V. Frunze wrote: “In order to be a good strategist, be it in pure politics or in military matters, special, specific qualities are required. The most important of them is intuition. . . .”³ I. P. Pavlov called intui-

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² Zh. Adamar, *Issledovaniye psikhologii protsessa izobreteniya v oblasti matematiki* [Investigation of the Psychology of the Process of Invention in Mathematics], Moscow, Sovetskoye Radio, 1970.
Dialectic unity of subconscious and conscious information processes is a morphologic, structural quality of the human brain. The subconscious operation of the brain, under the influence of consciousness, acquired a new attribute, which found its expression in intuition. Consciousness concentrates the thought resources of subconsciousness in the required direction. There are several ways of developing and expanding these control functions, even in relation to internal organs. Natural data are manifested, in all probability, to a considerably greater extent here than in the field of conscious thought; effective utilization of capacities produces education and knowledge. Knowledge, stored in the brain, is the material foundation for information models and for the transformation of these models. Man usually cannot directly control the processes that take place in the subconscious. It is an irrefutable fact, however, that thinking is facilitated by subconscious work, and subconsciousness is fortified by intensive conscious activity. The "extraction" of information from the subconscious into the conscious also requires training.

Subconscious information processes often proceed especially rapidly when consciousness is suppressed by overload or when it is disengaged enterly, for example, during sleep. Nature has wisely determined a definite relationship between information resources of the conscious and subconscious parts of the brain—optimal from the standpoint of survival of the species. In social activity, however, the evolutionary optimum is not always expedient, and this gives rise to its own contradictions.

The conscious thought of several persons may be combined for purposes of an overall increase in productivity. A second signal system (also a unique quality of man, although certain species of animals also possess it in its incipient form) serves this purpose. The "means" for subconscious processing of information from a group of people have not yet been combined, and the relation between them is very weak.

All these questions require research. Meanwhile one should be cautioned against an oversimplified attitude toward creativity, and against the sketchiness and impoverishment of dialectic thought. The rather general concept that "each decision of a commander must be creative," based on the nonrecurrence of details in military situations, is false from its foundation up. Man never finds himself in two absolutely identical situations. But does this mean that any action is the result of a creative decision? Hardly, and moreover, the exceedingly great variety of situations does not facilitate creativity, since it does not insure the accumulation of information relative to the properties of a given situation, in which a qualitative leap may occur in understanding the nature of the situation. Unfortunately, the tendency to classify any conscious—not to mention intentional—action under a heading of creativity, is widespread and has serious negative consequences: underestimation of education, experience, knowledge and skill.
Nor is it useful to try to include a number of associated subprocesses in the creative process. In the interesting and useful book on military methodology¹ the process of creativity is broken down into the following stages: statement of the problem, search for a creative idea, development (i.e. concretization) of the idea, and implementation of the idea. The proposed breakdown may be accomplished in a different order, since creativity is usually not characterized by continuity, consecutiveness and logic, but a leap occurs, which may be the result of simultaneous comparison and linking of a large amount of data in the form of variously grouped models.

Bourgeois philosophers and psychologists, negating the dialectic essence of creative thought, ascribe to it an obscure and mystic character. Quite often they conceal the emptiness, lack of content and futility of their theories with a collection of words that confuse concepts. Such categories as "creativity", "intuition", "skill", are used as synonyms. Clausewitz, for example, wrote that in war "mental activity vanishes from the realm of rigorous knowledge and is transformed into skill—in the broadest sense of the word, i.e. into the ability to intuitively select the most important and decisive of an innumerable set of objects and circumstances." One may conclude that skill is the capacity for intuitive selection. This conception has nothing in common with materialism.

Despite the uniqueness and nonrecurrence of military decisions, an analysis of century-old military practice makes it possible to systematize the factors that influence decisions. Here are a few of them:

1. Concentration (of forces, weapons, of any conditions or circumstances in time and in space).
2. Acceleration (of processes, conditions and events).
3. Disinformation (distractions, surprise).

The knowledge of these factors alone does not afford the possibility of analyzing a specific situation, but it may serve as an impetus, a starting point, a springboard for dialectic thought and stimulation of it. To construct a mental model of the decision means to mentally recreate the course of events in the assumption that the decision has been reached and implemented. This model should reflect the qualitative and quantitative relations of the stated factors with due regard for the feasibility of implementing them. Dialectic conversion of one factor to another, and combined utilization of several factors are possible. We are discussing here not only the functional or statistical relation among the factors, but also the sudden transition of one factor to another as it reaches a certain level.

The resolution of a contradiction is sometimes possible not through

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the reinforcement of some factor, but conversely, through weakening of it: deconcentration (dispersal), retardation of actions etc.

The rejection of close order formations in military actions and conversion to lines was the reaction to improvement of firearms and artillery. The warning “I’m coming after you”, which Prince Svyatoslav sent his enemies, was not so much an act of knightly chivalry as farsighted strategy: it was more advantageous for the well-armed and trained troops of Svyatoslav to fight a concentrated enemy than one dispersed in the steppes in small groups of nomads who had great mobility. Svyatoslav was not a bad dialectician and social psychologist: information about the threatened attack led the enemy to concentrate his forces.

Modern wars are characterized by deeper contradictions and greater variety of situations. This, of course, does not mean the contradictions are easier to conceal. Quite the contrary, the intertwining of political, military, economic and moral factors, which concerned only the higher echelons in past wars—front and army—now influence substantially lower level organizations. The missile submarine is not only a military, but also a political factor.

The decision to use a nuclear weapon involves the resolution of contradictions that never occurred in wars of the past. The moral aspects, including the guarantee of maximum safety to peaceful inhabitants, guarantee of radiation safety to friendly advancing forces, the vital time factor (precipitant use of tactical nuclear weapons can have just as serious consequences as a delay), and many other factors pose complex problems. These problems are examined in the capitalist armies from different points of view; some of them are ignored altogether, and this is also one of the factors of the situation which must be taken into consideration. In order to recognize objective contradictions, it is necessary to imagine the situation from the enemy’s point of view and to perceive it the same way the enemy does. This makes it possible to examine the dynamics of processes and phenomena that unfold in a situation, and then to discover the contradictions and penetrate into their depth.

The essence of a dialectic leap in this process can be imagined with the aid of a systems analysis model which includes several lines of thinking that may develop variously in time.

The first line (ascent) is the assimilation of facts that describe objective phenomena, their successive abstraction at different levels (all the way to the level of philosophy, of general ideas).

The second line is comparison of abstract concepts at various levels, the drawing of analogies, i.e. of the similarity or common features of events that differ in terms of meaning and physical content.

The third line is synthesis, i.e. the development of qualitatively new models of abstract character on the basis of the analogies that have been drawn. A qualitative leap occurs at this point through the combining of parts of different models into one model: new grows out of the old.
The fourth line (*descent*) is conversion from abstract models to a specific situation, detailing and defining of the latter.

It should be emphasized that a dialectic leap is impossible without thorough knowledge. Stanislav Lem, in his "Formula Limfatera" [Limfater's Formula] made the following mistake (probably intentionally): not only a "tempting perfection," but any intelligent behavior at all is impossible without preliminary training.

6. Conclusions

All three methods of thought—empirical, axiomatic and dialectic—operate simultaneously, interlacing, supplementing, negating and mutually controlling each other. The one that dominates in a given situation is the one that is the most productive from the standpoint of the thinking individual.

Let us examine the general features of the various methods (models) of thought, which allow us to use a single block diagram for picturing them:

1. All models require *a priori* knowledge. A priori knowledge completely defines the capabilities of empirical thought. Axiomatics, the method and tools for reaching a conclusion (in axiomatic thought) are included in a priori knowledge. Dialectic thought requires initial models; they are also a priori knowledge. All the methods require tools for evaluating the models and variations. The specific weight, however, of a priori knowledge varies. It is lowest of all in dialectic thought that has a few initial models; the remainder is achieved through their alteration and rearrangement.

2. All forms of thought are related to recognition, identification. In empirical thought the initial situation is identified with one of the situations that is stored in memory. In axiomatic thought it is necessary to successfully select the axioms which must be used in a specific case. In dialectic thought any attribute of a situation must be identified with an attribute of the *a priori* model.

3. All thought methods require an evaluation of the result attained from the standpoint of the problem being solved, i.e. evaluation of effectiveness. The thought process is unique and continuous, since it is constantly being supplied with new information from the sensory organs and from perception (of the first and second signal systems). But it is also intermittent, since the results of thinking are formulated as images and ideas at specific points in time. This dialectic contradiction may be related to the decision process: it continuously acquires new information, but the result is formulated and sent out intermittently and locally.

Thus, we have established the basic features of a systems analysis thought model and its basic elements. Now the problem is to expand the model, and isolate and describe its more detailed subprocesses.
Chapter 2. Classification of Decisions

Break down each problem you are trying to solve into as many parts as you can and as many as you need to solve them easily.

**Descartes.**

This rule of Descartes is not effective, since the art of separation does not yield to interpretation.

**Leibnitz.**

Any specific action is preceded by analysis and evaluation of the situation, then by formulation of a plan of actions and preparation for action, i.e., organization (of oneself and of one’s forces and equipment).

Situation evaluation—whether of external conditions, the enemy, or capabilities—is usually associated with preparation for a certain action, but is at the same time an independent problem. It is first necessary to acknowledge the truth (or falsity) of reports and then determine the sufficiency of data for attaining the goal. To evaluate a situation means to construct its model with a certain orientation and detailedness; to establish the important indices and decide relative to each of them whether it exists in a given specific situation. A given situation may be modeled and evaluated from different points of view, depending on the different purposes. The criteria for evaluation are determined by the purpose of proposed action. If information is complete and accurate and the criteria are unique, then, in accordance with what was said earlier, evaluation amounts to the reaching of a conclusion (deduction). The fact is that this never happens. Even when we are discussing our own forces it is necessary to acknowledge the insufficiency and inaccuracy of data which we have at our disposal; we are not able to determine with certainty—let alone—forecast the weather, road conditions, condition and performance of equipment, fatigue of the troops, their attitudes, morale, etc. Information about the enemy is usually not only incomplete, but even unrealiable in view of disinformation—intentionally erroneous data with which the enemy tries to confuse us. Disinformation may lead to a false deduction. In the presence of insufficient and inaccurate information it is impossible to formulate the rules for constructing deductions, since the rules depend to a large extent on the information.

Thus, we arrive at the conclusion that it is impossible to evaluate a
situation simply by means of deductions on the basis of judgments contained in initial information. There is usually no complete guarantee of being correct in recognizing truth; consequently, it is impossible to speak of a precise conclusion and interference of the will is required. Just as it is impossible to employ a single means of action, it is impossible to guarantee the absolute truth of some reports and absolute falsity of others in a complex, undefined situation. The very perception of information encounters a volitional barrier. Social experience gives us many positive and negative examples of the effect of the volitional factor on evaluation of the truth and content of communications. History records tragic cases of inexplicable disbelief of "obvious" facts (obvious—\textit{a posteriori}). No knowledge of history, however, can alter the nature of information and of human relations, since at its roots are the need for and the inevitability of willful action in the final stage of evaluation of information.

Thus we have established that evaluation of a situation includes the following steps: 1) recognition of the purpose of evaluation; 2) mental reproduction; 3) modeling of situation, mental consideration of justifications for willful actions related to evaluation; 4) willful action. These are all attributes of decision-making.

\textbf{The decision as to "What is the truth?" is defined as an information decision.} Situation evaluation, concealment of plans, and evaluation of the theater of military operations, the battlefield, equipment and the behavior of the troops is, in a word, information evaluation—all of these are information decisions.

The essence of an information decision may be formulated strictly as follows: The attributes of a situation are $B_1$, $B_2$, \ldots, $B_n$; they are complex and are related nonuniquely to reports $A_1$, $A_2$, \ldots, $A_m$. We are required to decide which of the attributes $B_1 \rightarrow B_n$ are true (for this purpose we must first decide which of reports $A_1 \rightarrow A_m$ are true).

It is sometimes said that such an approach to the problem contradicts existing notions about evaluating a situation on the basis of conclusions derived from available data. This argument is incorrect, since it is impossible to arrive at a simple conclusion. It is often said that different conclusions can be reached from the same premises. But such round about, inaccurate usage of the word "conclusion" can only lead to misunderstandings and serious mistakes. Even if a conclusion exists it is by no means always possible to reach it due to a sortage of time, unfavorable conditions, lack of the required equipment, etc.

An information decision presumes generalization and processing of information into a form that in most degrees corresponds to a specific problem of troop management. The commander of a fighter-interceptor division, for example, simultaneously receives from radar stations, air reconnaissance and ground observers information about enemy aircraft. As a result of processing this information and comparing with previous
information the commander develops his own concept about the enemy, his order of battle, makeup, etc., i.e., constructs a model. This is exactly what an information decision is. Consider the following simple example: a commander personally checked the flying techniques of a pilot and was left with a favorable impression. At the same time he receives contradictory reports about other qualities of the same aviator, which he was not able to check out. The commander’s final judgment about good qualities of the aviator is an information decision.

Let us consider some other examples. Suppose that a report was received concerning the concentration of enemy troops and revitalization of his air actions. Information decisions may consist in the assumption that the enemy’s concentration and air actions are facts, i.e., the reports are considered true. In order to answer the question as to the enemy’s intention to attack, a more general information decision is required. When arriving at such a decision, it is necessary to established whether or not there are enough indicators, and if not, it is impossible to arrive at a decision. In this case the information decision concerns the enemy’s intentions. However a more important question must often be answered: will the enemy attack, when, where and with what forces? In this case an information decision is made on the basis of comparison of intentions and actual capabilities, trying to foresee the events better than the enemy can.

We should note that assumptions made about the enemy do not constitute information decisions. Marshal of the Soviet Union G. K. Zhukov writes in his memoirs: “Thus, the enemy should be expected to organize a strike group on the Voronezh front . . .

“The enemy intends to carry out concentrated strikes in order to surround our troops . . .

“The enemy should be expected to attack toward the southeast in order then to advance northward.

“However the possibility is not excluded that the enemy will abandon the plan of attack this year and implement another plan . . .

“The enemy is not ready at this time for an all-out offensive. The offensive should be expected not earlier than 20 April of this year, and most likely during the first days of May”¹ (the italics are ours—V. D., D. K.). This text contains one information decision, in which it is said that “the enemy is not ready at this time for an all-out offensive.” The remainder is preparation for the information decision. The decision was made after determination of the enemy’s most probable plan of actions.

A reliable information decision is reached not only through rechecking and reconnaissance (which requires time that may not be available), but also penetration into the essence of the situation, ideology and psychology of the enemy.

When reaching an information decision it is essential to consider the

¹ G. K. Zhukov, Vospominaniya i razmyshleniya (Memoirs and Reflections), Moscow, Izdatel'stvo APN, 1969, pp. 473, 474.
possibility of misinformation. General of the Army S. M. Shtemenko thus describes instructions on misinformation, issued by the Headquarters of the Supreme Command in the early summer of 1944: "For the purposes of misinforming the enemy it is your responsibility to implement operational concealment measures. It is necessary to show a concentration of eight or nine infantry divisions on the right flank of the front, reinforced by tanks and artillery. . . . The enemy immediately bit on these two lures."1

Misinformation should take into consideration the individual and social psychology of the enemy, and it is aimed directly against willful action.

Let us turn now to the question of organization.

**Organizational decisions answer the question "What to be?"**

"Organization (. . . Late Latin organizo—to impart an ordered appearance, to arrange),—as defined in GSE*,—(1) Ordering, setting things up, structuring, putting something into a system . . . (2) . . . A society, a union of people or social groups . . . for solving common problems, achieving common goals . . . (3) Structure, interrelationship, mutual arrangement, correspondence of parts of some whole." Military organization is intended for waging war, training personnel, discussing certain problems, developing technical systems, etc. Organization may be either permanent or temporary. The establishment of any organization is aimed at pursuing a certain goal (or several goals). The basic requirement imposed on organization consists in the execution of its functions, which derive from its purpose. The requirements also include the limitations imposed during establishment of an organization on the number and makeup of personnel, method of deployment, communications, etc. These requirements are sometimes undefined, for example, if an organization is established for some long-range purposes which are not completely clear.

Let us assume first of all that the goal is known, the limitations are given and a criterion for evaluation of the organization is known. The problem consists in setting up the best organization. How many forms of organization corresponding to the conditions can there be, and how can they be compared? If the permissible number of people in an organization is large (100 persons for example), then there is no need for mathematical calculations in order to understand that the number of possible variations of an organization exceeds hundreds of thousands and millions. However, the number of persons, their specialties, service rank, etc., may not be completely determined, and then the number of possible variations increases even more. But there is more to it than that: the purposes and criteria of evaluation may be quantitatively and qualita-

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1 S. M. Shtemenko, *General'nyy shtab v gody voyny* (General Headquarters during the War), Moscow, Voyenizdat, 1968, pp. 233, 234.

* GSE—Great Soviet Encyclopedia.
tively incomparable, and then it is not clear to what criterion preference should be given. Even for comparable criteria, however, the situation is not much better: the importance of a given criterion may vary in different situations.

The conditions under which newly created organizations will function are not completely known. When a group is organized for carrying out military actions we may only approximately determine the situation. Furthermore, we inevitably become accustomed to established forms of organization and sometimes fail to consider the overall complexity of reorganization in connection with new assignments and goals.

The following problems, therefore, inevitably arise in the development of a new organization:

1) incomplete definition of goals and purposes;
2) incomplete determination of conditions;
3) very large (practically infinite) number of possibilities.

Is it possible under these conditions to work out the optimal or even workable organization in a purely logical way? It is clear on the basis of considerations made above that this cannot be done; the optimal organization either does not exist or cannot be found. Even though the development of an organization theoretically may be considered a mathematical problem under ideal conditions, it is practically impossible in most cases even to formulate. The development of an organization includes conjecture, interpretation, simulated operation of the new organization under various conditions and, finally, discussion of the reasons for selecting the final version. This is what decision-making is all about.

An organizational decision consists in determining the structure, distributing functions among the offices and responsible persons, establishing a chain of command and communications system. The most common organizational decision is the structural decision since all others are related in some degree to structure.

Since an organization is based on knowledge of the situation, an organizational decision is preceded by an information decision. Organizational decisions sometimes precede the carrying out of combat operations or training measures, sometimes are concurrent with them and sometimes are implemented after their completion. During the Great Patriotic War organizational decisions related to personnel replacement, replacement of commanders and reorganization of subdivisions had to be made continuously. Decisions of major importance, determining the outcome of the war, were also made.

Organizational decisions include those that are related to the composition of the troops, structure and time of operation of an organization. The formation of the Supreme Command Headquarters and the abolishing in the final days of the war of the Institute of Headquarters Representatives were organizational decisions. Organizational decisions also include the implementation of combat training programs, determi-
nation of the structure of the training programs in higher institutes of learning, change of personnel rosters and transfer of personnel. The characteristic feature of organizational decisions is their orientation toward a comparatively broad range of situations. Even an ad hoc organization may encounter various conditions during the performance of its assignment. The essential qualities, therefore, are adaptability (the capacity to adapt to a situation) and stability with respect to extraneous influences.

Operational decisions, which are the culmination of a commander’s activity, are among the most complex and important decisions. Operational decisions answer the question “How to act?”

The class of operational decisions includes all forms of decisions related to combat activities of the troops, in particular: determination of the purpose of military operations; establishment of the level of combat readiness; determination of the direction of a main strike; assignment of forces, weapons and the method of combat; establishment of missions for the troops; system of interaction, etc.

The most common of operational decisions is determination of purpose. The other elements of a decision and the criterion for evaluation of effectiveness are established on the basis of purpose. Purpose is not an entity in itself, but is the consequence of a more general, higher goal. The goal of war is determined by the political goal; the commander-in-chief formulates a goal for a subordinate, who in turn divides it into partial goals, i.e., “subgoals.” A goal, however, is not an external factor with respect to an operational decision, but is a part of it.

The history of warfare is full of examples of decisions which led to defeat due to erroneously stated or understood goals, as well as to brilliant victories, gained by virtue of successfully formulated goals.

The disagreement between Kutuzov and other members of the military council in Fili stemmed basically from differences in understanding the goal of the war. For Kutuzov, the chief and completely defined goal consisted in defeating the enemy and driving him out of Russia. Those who opposed him proceeded from narrower goals (prestige, victory in battle and the fate of Moscow).

The determination and precise formulation of a goal in the making of operational decisions are very difficult tasks.

The other elements of an operational decision are not simply the consequence of the goal; they interact with the goal and with each other, as a result of which a decision is reached. An operational decision is made on the basis of comprehensive analysis of facts, chances and opinions. In many cases the initial goal, seemingly clearly formulated, undergoes significant changes during preparation of the operational decision; additional goals and subgoals emerge. It often turns out that the initial goal is demoted to a lower priority. Operational decisions may concern the carrying out of maneuvers, training measures and human
relations. It should be understood that an operational decision always determines an action, whereas an organizational decision is not related to specific actions, their content or forms.

The set of decisions of military leaders of various ranks, operating in the same chain of command, comprises a hierarchy of decisions that determines how these decisions are linked together. Various tendencies may prevail in the formation of a hierarchy:

1) from bottom to top (i.e., decisions are made at higher levels on the basis of decisions made at lower levels); this type of structure is most characteristic of informational decisions;
2) from top to bottom, characteristic of organizational decisions;
3) counterflow, when decisions at lower levels develop (in conformity with their needs) and implement higher level decisions while high-level decisions are reached after having considered previously-made decisions at lower levels; this type of hierarchical structure is characteristic of operational decisions.

Decisions circulate within the hierarchy as flows of information, which provide for the input and compatibility of new data. The living, continuously changing system of decisions, along with the causal relations among them, comprises the logical foundation on which all the activity of the troops is planned. Since each decision is made on the basis of its connections with other decisions, especially the next higher decision, limitations arise which determine the “degrees of freedom” of a given decision. These limitations ensure the agreement of decisions at any given level of the hierarchy. A decision may vary within the given “degrees of freedom.” It should be pointed out that imposing limitations is not sufficient for obtaining agreement on decisions. It may turn out that all limitations are satisfied, but there is no agreement, as required. A well-organized and coordinated style of thinking on the part of the commanders is also required. The content of decisions from the higher levels of the decision hierarchy and control from top to bottom are very important. By this control we mean approval of lower level decisions at higher levels.

A general classification of decisions is presented in Figure 4. Why is classification required and what is its result? The purpose of classification is step-by-step breakdown of an assignment. It is essential as a stage of knowledge.

Which approach should be taken depends on the type of decision. It is often necessary to make decisions of far reaching scope, which include information, organizational and operational parts. Then the classes of decisions emerge as stages and elements of a general decision; corresponding techniques must be employed at each given stage.
Figure 4. Classification of decisions.
Chapter 3. Information Decisions

Knowledge is knowledge only when it is acquired by the powers of one's own mind, and not by memory.

L. Tolstoy

1. Basic Concepts

An information decision determines what data are considered true. Information reflects objects or events. In other words, it is a model of what has occurred, is occurring, or may occur. A model may contain many or few details, depending on the amount of information, but it cannot be an absolute representation of a situation. A model is a simplification. A commander does not need an absolute representation of a solution in order to manage his troops: too many details simply make his job more difficult. The degree of detail should correspond to the specific problem: the model should be adequate. Consequently, the making of an information decision means not only the separation of correct information from incorrect (from misinformation), but also intelligent generalization and elimination of superfluous details. No decision can increase the number of details.

The making of an information decision also presumes evaluating the quality of the decision, its reliability and level of generalization. The commander must know how close his decision is to the truth. It is not enough to indicate in an information decision that the enemy has concentrated approximately 100 units. A more accurate determination must be made: 100 ± 5 or 100 ± 20.

An information decision is the initial data for operational and organizational decisions. It should be borne in mind that when making an information decision, the commander may be dealing with matters about which he previously had no knowledge, and with matters he may not have known even existed. This introduces uncertainty, which complicates decision making. On the other hand, an information decision may be derived from specific information. It is indeed in relation to this information (and not to presumptions) that a decision must be made. Conclusions about subsequent events may constitute a new decision, but may not enter into a decision concerning the truth of factual data.
In 1941 Germany transferred huge contingents of forces to the East, simultaneously spreading the story that this was done for the purpose of concealing preparations for an invasion of England. Our command had information both about the concentration of German forces on the boundary and about the rumors being circulated. How could an information decision be arrived at? In the case at hand it would have had to contain two independent decisions:

1. Germany is concentrating forces (in a certain composition) on the border of the Soviet Union, transferring them from (certain) areas.
2. Information has been received that the diversion of troops to the East is aimed at concealing an invasion of England.

The combining of the two decisions into one is impossible. In particular, the decision that "in the near future a war will begin (or will not begin)" cannot be made, since there is insufficient information and it is different in nature: assertion (1) speaks of facts, whereas assertion (2) establishes only assumptions about intentions.

Definite "layers" of decisions, characterizing the depth of penetration into a situation, should be distinguished within the information class of decisions:

1) information decisions about a factual situation;
2) information decisions concerning information the enemy has;
3) information decisions concerning the enemy's intention.

An information decision, as already mentioned, is a faithful model of what will take place.

An information decision about the enemy's possession of certain data on our forces may be made on the basis of objective information, for example: "It has been established that during the period of 1700 to 2200 hours the enemy monitored telephone conversations that were not in code." On the basis of this information it may be decided that the content of the conversations, which were conducted from 1700 to 2200 hours, is known to the enemy. If the conversations were encoded then it is necessary to consider the security of the code and the time available to the enemy for decoding; it is then decided that the enemy possibly knows the content of the conversations, and this must be taken into consideration. An information decision about the enemy's intentions also requires direct data: information about the "Barbarossa" plan would have made it possible to arrive at the decision that Germany intended to wage war on the Soviet Union.

It should also be pointed out that primary "doctrinal" views sometimes play the predominant role in great operational-strategic questions, and this may lead to conservatism that at first glance cannot be understood. Moltke disclosed the path of the attack on France through Belgium, but during the two decades between the First and Second World Wars nothing was done to prevent an invasion from this direction. Hitler implemented Moltke's plan.
The composition and structure of actual data have a significant effect on the method of decision making. Consider, for example, the following hypothetical situation. Suppose that two countries, L and M, have nuclear missile attack capabilities. The existence of nuclear missile weapons can be determined on the basis of various indirect indicators; let us assume that M has the following information:

1. Scientists in L have published profound works on nuclear physics, in particular concerning thermonuclear processes; publications have ceased to appear in the last few years.
2. Underground nuclear blasts have been detected in the territory of L.
3. Intense study of satellite orbital paths over the territory of M is underway.
4. Intensive construction of installations resembling launching facilities is underway in L.
5. The mining and processing of nuclear raw materials have been stepped up in L.

On the basis of all these data an information decision concerning the situation can be made: “L has nuclear missile weapons.”

Suppose a publication appeared in the open press of L concerning the nuclear missile forces of M, which is very close to the truth. This enables M to make an information decision: “L knows that M has nuclear missile weapons.”

The question of intentions of one of the sides to deploy its weapons is particularly complex, since it is related to the continuously changing political situation inside and outside the countries, and also to the struggle of groups inside the capitalist governments. The development and expansion of nuclear missile forces indicate the intentions of L, but this in itself may not be sufficient for an information decision: information to the effect that other governments also have nuclear weapons may change L’s intentions. However, to make a specific case, let us assume that L has openly declared its intentions to start a war (and this happens). M may make the following information decision: “The enemy intends to unleash a nuclear attack in the near future.”

Before acquiring information on the basis of which a decision must be made, the commander has a priori information and an a priori model of the situation; the information decision is made in consideration of these data. Previous decisions are a priori in relation to each decision; each decision generalizes previous ones and embodies them. A previous decision may be revoked in particular cases.

Consider, for example, a Japanese commander of the Second World War. His a priori model of a situation included the enemy, with infantry, artillery and bombers. If the discussion concerns a man with a rather narrow scientific-technical outlook, then he could not have had any idea about atomic warfare (even in most hypothetical forms), and in this
regard he had no *a priori* information. Meanwhile, if the discussion concerns an objective person with a sober mind, such a person would have been able to recognize his lack of information and upon receiving reports about an explosion he would have take it seriously, even if he had not believed it; in this case the *a priori* information consists in evaluation of personal competence. If he is an erudite man, familiar with achievements in physics and technology, then he could have had *a priori* knowledge about the development of the atomic bomb and even about certain properties of an atomic explosion. With such a knowledge he would be able to analyze a report about the atomic bombing of Hiroshima much more completely and thoroughly; his information decision would be more reliable and his situation model more complete. But if we are talking about a commander who being uninformed about scientific and technological achievements, does not recognize and acknowledge his lack of knowledge, then his *a priori* information is equal to zero. If such a commander had received a report about an atomic bomb blast, he would have taken it either as a malicious lie or as a celestial omen; in either case the consequences for his subordinates would have been disastrous. Thus, the correctness of an information decision depends on *a priori* knowledge and on the proper evaluation of the level of knowledge. Since each decision becomes an *a priori* one in relation to the following one, it is essential simultaneously with the making of an information decision to evaluate its completeness and reliability. The entire process of training a man, a staff or a key system (including people and equipment) consists essentially in the transmission of a series of information decisions, each of which complements or connects the preceding decision. Therefore what we have said above applies to any knowledge, regardless of whether it is concentrated in the program of a computer or is retained in the human brain.

The need for evaluation pertains not only to *a priori*, but also to new operational information: when analyzing any report it is necessary to determine how much confidence can be placed in it. This is usually done on the basis of the characteristics of the sources of information. Sources may be people, documents and technical systems. Each information source should itself make an information decision before transmitting a report: what to transmit. A mistake, if one occurred, is difficult to correct. Any selection of signals is an information decision. Therefore, making the next information decision at a higher level requires a knowledge of the probability of error in the lower-level decision.

The properties of information sources are characterized with the aid of the following quality indices: range or zone of operation; completeness of representation of the situation; accuracy and detail ("resolution"); reliability of the representation of the situation.

The zone of operation determines that part of a situation (range of activity, part of space or territory) to which the information pertains. The zone of operation is limited in space, in time and in terms of the
composition of indices with which the source operates. Technical systems, for example, cannot give information about the moral state of enemy troops (communications or eavesdropping systems are not sources of information), but without technical systems man cannot observe the ballistic flight of missiles. If an information source includes both technical systems and people, then its zone of operation will be determined by engineering and psycho-physiological capabilities.

The completeness of representation of a situation determines the ability of an information source to encompass all objects, indices and properties located within the zone of operation. For a radar station, for example, this is the number of targets, and for air reconnaissance it is the number of objects detected. If the objects are equivalent, then a sufficient measure of completeness of representation may be a relative evaluation (the percentage of detected objects, for example). In the case of nonequivalent objects (indices) it is necessary to know the ability of the information source to detect, observe and determine the significance of the objects. In order to evaluate the completeness of representation it is necessary to formulate the task assigned to the information source. Suppose that this task consists of discovering the type of weapons of some group. The objects of the information will then be aircraft, tanks, artillery, missiles, etc. The representation will be complete if the observer does not omit in his reports any of the types of weapons which the group possesses; in this case he is not responsible for determining the number of aircraft or missiles. If a radar system is given the task of detecting ballistic missiles, then the completeness of representation will be determined by the percentage of ballistic missiles detected; the fact that data on artificial earth satellites and rocket-propelled aircraft may be presented at the same time has no bearing on evaluation of the completeness of representation.

The accuracy (detail) of representation is determined on the basis of some scale, introduced beforehand, by means of which the object of the information is evaluated. The scale may be in space (coordinates), time (time of observation), or it may be a special scale (scale of the types of military objectives or situation danger indices). A report of the form “20.5 at 1900 radar picked up in vicinity of Bezymyannyy Island 3 bombers and 6 interceptors, flying in formation toward the southwest” is an example of the simultaneous utilization of several scales: a) spatial (Bezymyannyy Island); b) time (20.5 and 1900); c) types (bombers, interceptors); d) quantitative (3 and 6 aircraft); e) orientation (southwest flight); f) mode of operation (combined flight). The ability of an information source to determine, let us say, the types of airplanes is not the same as the ability to measure their coordinates. Therefore, in order to give an absolute evaluation of the accuracy of representation it is necessary to use yet another scale, in which the significance (operational weight) of each of the scales is signified. With the aid of such a scale
all forms of data can be organized and reduced to a single dimension, which yields a single quantitative evaluation. If only the coordinates of a target are significant (in this case all other indices of a target should be stipulated beforehand), then the accuracy of representation may be characterized statistically (mean squared error).

To simplify the system of quality indices the completeness and accuracy of representation may be reduced to a single index. For this purpose it must be stipulated beforehand that the object being represented is to be considered only when an error in the representation does not exceed some value. A generalized index is more approximate, but in many cases it is more convenient.

The reliability, credibility and truth of an information source are usually determined by the opposite index—the probability of the release of false data. For example, reliability may be evaluated as the number of false targets read out by a radar system per unit of time, or the probability of a false alarm.

Reliance on each new report is determined by the quality indices of the source of the report. The quality indices of technical data sources are statistical characteristics, determined on the basis of analysis of their parameters and conditions for combat application. If a data source is a man or a group of people the situation becomes more complex. First of all, the “parameters” of people are much less stable than those of technical systems; they depend on frame of mind, physical state, etc., in addition to personal attributes. Second, various qualities depend on a person’s level of training and understanding of the problem; therefore they are subject to rather rapid changes. Third, mutual relations, the structure of the group and form of communications are of great importance for group data sources, and these factors may vary during performance of an assignment. In evaluating the equality indices of data sources in which people participate, therefore, there is usually a greater (compared with technical systems) uncertainty, which itself must be evaluated. For example, an officer is assigned the task of processing newspaper reports in which the behavior of troops of a probable enemy is described. It is known that he obtains, on the average, data from 40 out of 50 newspapers from one group of translators and from 30 out of 50 newspapers from another group (both groups of translators perform their own assignments, but interaction with the first group is more fruitful). This means that the “completeness of representation” of newspaper information varies from 0.6 to 0.8 under the various working conditions of the officer (different translators).

Evaluation of quality indices is structured on the basis of previous activity. An objective evaluation requires statistical processing of data that characterize the activity of a person with consideration of the conditions under which this activity was performed. Such processing should be continuous so that the evaluation will not become outdated. In addi-
tion to objective evaluation, which in view of insufficient data is usually not complete, subjective evaluation is employed. Subjective evaluation considers the experience gained from working with others and personal opinion. Comparison of objective and subjective evaluations makes it possible to better analyze the properties of a data source and to pay proper attention to the data which it makes available.

In addition to quality indices, the means used for obtaining the data and the conditions under which the data were gathered must be taken into consideration. A partial characteristic of conditions (time, location, circumstance, enemy counteraction, etc.) may be contained in the report itself. The reliability of incoming data depends not only on the source of the data, but also on the communications channel; garbling of reports during transmission must also be taken into consideration. Communication channels may be characterized by the same quality indices as the data sources. Technical channels are usually characterized by transmission speed and the percentage of garbling. Technical and semantic distortions are distinguished. Technical distortions lead to a reduction in the completeness of representation (a report becomes unintelligible and cannot be used) and in the accuracy of representation (digital data are distorted). Semantic distortions lead to a reduction in reliability (a false message is received) and reduction in the completeness of representation (a transmitted report is lost). Semantic distortions are more dangerous. When technical data transmission systems are used semantic distortions usually occur rarely; such distortions are more probable when people handle communications. Communications systems are often employed by the enemy for misinformation, and in this sense they are more vulnerable. This is particularly true of operational misinformation, which is directly related to the organization and course of combat operations. While much importance was attached in past wars to documental misinformation, transmitted through diplomatic and intelligence channels, emphasis is now placed on technical misinformation, organized by special means. It is not easy to recognize such information, and for this reason it is extremely important when protecting technical systems, to know how vulnerable they are to misinformation.

In analyzing a report, it is necessary to consider how its reliability and accuracy are influenced, both by the information sources and by the communication channel. A relationship may exist between the source and the channel, and it must be considered. A message can be written in such a way as to compensate to some extent for the deficiency of a communications channel. In the final analysis each message must be given a corresponding evaluation of its reliability. This evaluation may be statistical (valid, on the average, for a large number of uni-typical messages) or it may pertain only to a given specific report.

Statistical evaluation of a message to the effect that “4 enemy missile submarines have been detected” may be given with the aid of the mean
squared error, evaluation of the number of submarines, or in greater detail with the aid of the distribution of the probabilities of error (Figure 5). The curve seen in Figure 5 (integral law) says that in a report about 4 submarines the probability that there are more than one of them is close to 1, more than two—0.95, more than three—0.8, more than four—0.3, and more than five—close to zero. A “limit” evaluation of this message may appear as follows: “There is a report of 4 submarines; it is known that there are between 3 and 5 of them.” The boundary numbers here are arrived at with consideration of the quality indices and specific observation conditions. It is more difficult to evaluate the reliability and accuracy of reports that are the result of repeated information decisions in various instances. The number of such instances increases as the military rank and the responsibility of the commander increase. Therefore, care must be taken to ensure that the reliability of a message forwarded previously be controlled and considered at each step of an information decision.

Figure 5. Probability of error distribution in evaluating the number of ships in a report where \( n = 4 \).

If messages about a given object arrive from different information sources, evaluation should be generalized. Information usually arrives from sources that have substantially different quality indices. For example, a division headquarters may receive a report concerning enemy troop concentration in a certain region according to air reconnaissance and intelligence agents. This report should be generalized and transmitted to army headquarters. Since the decision is made at division headquarters, it becomes a source of information. What reliability should be ascribed to the message? If the initial data sources are independent in terms of methods and conditions of observation (such independence
apparently exists for air reconnaissance and intelligence agents), then the resulting reliability is calculated according to known mathematical methods in the same way as for independent events. But if a dependence exists between the sources, then it must be taken into consideration. It is particularly inexcusable to have information that is received by one source duplicated by another source, and received by an addressee as two independent reports. Such a relationship between messages can usually be discovered, but more complex cases can occur. For example, air reconnaissance is conducted by two crews in conditions of poor visibility. A similar error may be committed by both crews in view of the difficult observation conditions. The element forming the relationship between the messages in this case is the same weather. The crews must report this, but they themselves cannot establish a quantitative estimate of the degree to which their data are related. This problem must be solved at a higher level. A dependency may also exist between technical data sources. For example, two radar stations, located at different positions and observing the same ballistic missiles, may have identical errors due to the effect of the ionosphere. A relation between the errors can be determined with the aid of a special ionosphere station.

When organizing reconnaissance, the commander must take measures to minimize the dependence between information sources. This may be done in various ways: by using technical systems that operate on different physical principles, by organizing independent and unrelated reconnaissance groups, by monitoring report traffic, etc. The absence of a dependence between data sources is one of the prerequisites both for high data reliability and for efficient utilization of forces and resources. This, as we shall see later, greatly facilitates the discovery of misinformation.

To prepare an information decision it is important to know its logic structure. An information decision is, by nature, a multialternative one: each situation model is an alternative. Any message, however, may be broken down into elements, each of which requires an alternative solution: true or false. Thus, a multialternative decision may be represented as a set of bialternative subdecisions. But these subdecisions will be mutually dependent. To explain the above statement let us consider the following example: The following message is received: “The enemy is concentrating missile-carrying aircraft at airfields A, B and C in the following makeup: A—2 bomber flights; B—1 bomber and 1 fighter flight; C—3 flights of fighter a/c.”

This message may be broken down into the following components:

1) the enemy is concentrating air power (in order to make a decision on this point we may compare a priori data on how many airplanes were previously based at the airfields with the new data; this part of the message may be considered independently);

2) 2 flights landed at airfield A;
3) 2 flights landed at airfield B;
4) 3 flights landed at airfield C.

It must be determined whether the assertions in points 1–4 are true. For each point there is an alternative, true or false (the variations of landing of a different number of flights at the airfields are not considered; if they need to be examined, then the corresponding assertions are entered in the appropriate table). Thus, a multialternative decision is transformed into four bialternative ones. We note that if negative decisions are made for points 2, 3 and 4, then it is impossible to arrive at a positive decision on point 1, since a logic contradiction arises. This is an element of relation. Moreover, point 1 is of independent importance: if a flight from airfield B landed at airfield A, then the assertion in point 2 is true, whereas the assertions in points 1 and 3 are false. We may operate with dependent decisions, but quite often it is possible to get along without these tie-ins. By replacing point 1 in our example by several points, specifically: 1) the number of aircraft at A increased; 2) the number of aircraft at B increased; 3) the number of aircraft at C increased, then we see that the need for point 1 vanishes and the decisions become independent. It is not always necessary to supplement the composition of the decisions; it is often sufficient to formulate the alternatives differently in order to exclude connections.

An information decision is easiest to make when there is a minimum number of bialternative subdecisions that are independent of each other. Then the decision on each alternative is simultaneously a part of the overall decision, and the decisions on all alternatives comprise a general information decision.

The conversion of a multialternative decision into a simple one, i.e., into a minimum number of independent bialternative decisions, is a part of the overall technique of preparing information decisions.

The following basic methods for preparing information decisions may be proposed on the basis of theory and analysis of experimental data:

1) comparison of data (correlation method);
2) filtration of data;
3) situation recognition.

2. Comparison Method

The data comparison method is a multistep method. It is depicted diagramatically in Figure 6.

The first step is the grouping of the data.

Data are best grouped by reducing them to tabular (matrix) form, in which the decisions and alternatives are arranged vertically and the data sources are arranged horizontally. The content of messages is inscribed at the intersections of the rows and columns (Table 1). A message matrix should be constructed in such a way that it contains all available
data (regardless of the reliability of the source). It should also contain all possible information decisions related to the situation (regardless of the quality of the data relevant to this decision).

### Table 1.

<table>
<thead>
<tr>
<th>Sub-decision (bi-alternative)</th>
<th>Data source</th>
<th>Number of confirmed bombers at airfield A increased</th>
<th>Number of confirmed fighter a/c at airfield B increased</th>
<th>Number of confirmed bombers at airfield C increased</th>
<th>Air reconnaissance, flight No. 1</th>
<th>Air reconnaissance, flight No. 2</th>
<th>Radar reconnaissance</th>
<th>Ground observation post</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Confirmed. One flight landed</td>
<td>Unconfirmed</td>
<td>Confirmed</td>
<td>Confirmed</td>
<td>Unconfirmed</td>
<td>Confirmed</td>
<td>Between 20 and 40 airplanes landed Confirmed. Type of airplanes not recognized Unconfirmed. Observation conducted under conditions of jamming</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unconfirmed</td>
<td>Unconfirmed</td>
<td>Confirmed</td>
<td>Confirmed</td>
<td>Unconfirmed</td>
<td>Confirmed</td>
<td>Confirmed. Two flights landed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confirmed</td>
<td>Confirmed</td>
<td>Confirmed</td>
<td>Confirmed</td>
<td>Confirmed</td>
<td>Confirmed</td>
<td>Confirmed. Two flights landed.</td>
</tr>
</tbody>
</table>

If no data are available on a certain problem from some sources, zeros are entered in the corresponding positions.

Special emphasis should be placed on the precise and clear description of observation conditions which are included in the reports. A document of the type Table 1 is the basic and often the only tool for further operation, and therefore it must be written very carefully.

The second step is determination of the weight coefficients.
Expertise is one of the methods. However one cannot rely on experts for everything. Psychologists have established that man can satisfactorily determine the probability of events with which he is acquainted, but he cannot correctly use these probabilities for decision making. Each person forms his own perception of a desired decision, and he tries to justify his perception by supporting it with data on events. People are rarely without prejudice if they know that they themselves must make a decision and answer for it, and the method of preparing information decisions must take this peculiarity into consideration in cases when expertise is presumed.

When determining the operational weight (importance), the characteristics of data sources and observation conditions must be considered. Weight may be represented mathematically as the probability that a report is true. If the observation conditions are favorable, then the weight is equal to source reliability (i.e., to the probability that the source gives correct reports). In other cases the quality of observation is considered through a conventional probability, which may be evaluated either by the observer himself (the operator of a technical observation system), or by the resolving system (group of people) on the basis of the content of that part of the message in which the observation conditions are described. The formal method of determining weight consists in the following: The factors that may influence the reliability of a message are determined. Each factor must be made to correspond to some number (probability), which indicates the effect this factor has on the reliability of the message. Then the presence of the corresponding factor (or the extent of its participation) in the observation is determined. The conventional probability of truth of the message is calculated on the basis of the assumption that the factors are independent. The operation which determines the weight of each factor may be performed by a computer if input data are available. Such data comprise a part of the message for technical observation systems (for example, the probability of correct detection and the probability of false alarm for radar systems).

Thus, the basic idea behind determination of the weight of a report consists in simplifying this problem by breaking it up into the series illustrated in Figure 7. Sometimes it is easier to arrive at a general evaluation of reliability without going into such a detailed analysis of a message.

Figure 7. Determination of weight of message: a—single report; 1—expansion of message into elements (basic independent parts); 2—determination of factors that may have an effect on each part of message; 3—determination of effect of each factor on reliability of the message; 4—determination of conditional probability of truth of message; 5—conversion to accepted units of weight.
Such analysis is unavoidable when the computer is used, and its detail is determined by the participation of people in any given step of the operation. After the weight of a message has been determined the data may be reduced to more compact form of the type in Table 2. An alternative decision is denoted by the symbol "—" above the figure. A weighted coefficient that indicates its degree of reliability corresponds here to each decision.

Table 2.

<table>
<thead>
<tr>
<th>Decision</th>
<th>Data source</th>
<th>Air reconnaissance, flight No. 1</th>
<th>Air reconnaissance, flight No. 2</th>
<th>Radar reconnaissance</th>
<th>Ground observation post No. 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bombers at airfield A increased</td>
<td>0.8</td>
<td>0.3</td>
<td>0.9</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Number of bombers at airfield B decreased</td>
<td>0.9</td>
<td>0.4</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Number of bombers at airfield C increased</td>
<td>0.7</td>
<td>0.7</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

The third step is the combining of data pertinent to each decision. Two methods are used here: Calculation of total probability and amalgamation.

The total probability of truth of a decision is calculated according to probability theory. The sources of messages may be dependent, and the relation between them must be taken into consideration. For this purpose the dependent sources are combined into independent groups and the reliability of the messages from each group is calculated. The approximate form of the result of combining of data is illustrated in Table 3.

Table 3.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of bombers at airfield A increased</td>
<td>0.75</td>
</tr>
<tr>
<td>The number of bombers at airfield B decreased</td>
<td>0.82</td>
</tr>
<tr>
<td>The number of bombers at airfield C increased</td>
<td>0.95</td>
</tr>
</tbody>
</table>

The fourth step is comparison with previously established threshold values. The threshold levels are selected on the basis of experience, i.e., of a priori data pertaining to the situation, and in consideration of the importance of the decision. A priori data are used for selection of the thresholds.

Two thresholds are established for each decision: upper and lower. The size of the upper threshold level has to consider the degree of risk related to a positive decision. The upper threshold is the
guaranteed threshold and determines the increment of information (compared with the _a priori_ information), which is required for complete certainty. If the weights are determined through probability, and the _a priori_ probability of an event is, for example, 0.7, then the upper threshold level should be of the order of 0.8-0.9 or higher. Indeed, the absence of _a priori_ information makes it possible to ascribe to each alternative a probability of 0.5 (random choice). If the _a priori_ information makes it possible to increase this probability by 0.2, then it is natural to require that as a result of observations the increment will not be smaller. This, of course, is a very approximate explanation, which only illustrates the essence of the problem. The _a priori_ probability of an event may turn out to be less than 0.5, and consequently we favor the opposite alternative prior to observation. In this case, in order to be sure that the event takes place, a higher threshold is required. If the total probability does not reach the lower threshold the message is discarded. The lower threshold level is established on the basis of analogous considerations: the higher the _a priori_ probability and the greater the responsibility, the lower the threshold.

A decision is made on the basis of comparison: if the weight coefficient exceeds the upper threshold the alternative is taken, if it is below the lower threshold it is rejected, and in the intermediate case more data (additional reconnaissance) are required.

**The concluding step** is compilation of Table 4, in which are entered only the alternatives used for making decisions.

**Table 4.**

<table>
<thead>
<tr>
<th>Decision made</th>
<th>The number of bombers at airfield A increased by one flight</th>
<th>The number of bombers at airfield B increased</th>
</tr>
</thead>
</table>

Table 4 is used as the basis for constructing a more general description of the situation, which combines decisions made, decisions not made and questions arising as a result of decision making. The description contains a definitive part and a nondefinitive part, requiring additional reconnaissance and new decisions.

Amalgamation (literally: refinement) is the method used for weighing information from various points of view. Suppose that a quadruple alternative decision is being examined by three experts, to each of which is ascribed a weight, corresponding to his competence (from 0 to 1). The experts may analyze various aspects of the problem or points of view. Computer programs may be used instead of experts; their significance is also weighted. Each alternative is evaluated as +1, 0, −1. As a result we obtain Table 5:
Table 5.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Weight of evaluation</th>
<th>0.4</th>
<th>0.8</th>
<th>0.6</th>
<th>Summary weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>-1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>-2</td>
<td></td>
</tr>
</tbody>
</table>

The alternative having the maximum weight is accepted as the decision.

The method described above may be used for developing a program of operations for both man and computer.

3. Filtration Method

Let us turn now to the filtration method, a diagram of which is depicted in Figure 8.

The essence of filtration consists in decision making on the basis of comparison of reports with a set of previously formulated (a priori) independent characteristics, to each of which is ascribed a weight (significance). This set comprises the filter. The filter is a time-tested system of semantic and logical relations between the properties of a situation, object, event, phenomenon and their external manifestations and attributes. If the information satisfies this system it is considered reliable, but if it does not satisfy the system it is considered unreliable; if any doubt exists a decision cannot be made.

The characteristics that are included in a filter are termed the parameters of the filter. For example, a filter may consist of two characteristics associated with the preparation for an offensive: the concentration of forces and the concentration of equipment. If a message arrives concerning the enemy’s intention to begin an offensive simultaneously with a message that the enemy is withdrawing or dispersing its forces, then these messages do not pass through the filter and no decision is made on them. Only the data which are related to filtration indices are separated out. These data are classified and their reliability is evaluated. Then a separate decision is made on each of the parameters of the filter: the corresponding characteristic is or is not present. An information decision is made on the basis of confirmed characteristics by comparing their summary weight with the threshold.

The fundamental difference between the filtration method and the comparison method is the fact that the content of possible decisions is formulated beforehand, while the input information is analyzed on the basis of available characteristics. The characteristics to be evaluated in the
previously examined comparison method were determined during analysis of the information. The chief advantage of the filtration method is its relative simplicity (there is no need for a complicated and ambiguous procedure for determining the compared indications in various messages). The disadvantage of the filtration method is that information not pertaining to the parameters of the filter is not used. This encourages a certain amount of conservatism and disregard for unusual information, but that is the price of simplification. It should be pointed out that the independence of the indices of a situation does not mean that the data about these characteristics are independent. Reconnaissance results themselves may be mutually dependent, and this explains the basic complexity of the procedure.

Figure 8. Diagram of filtration method: A—input data; 1—grouping of data; 2—separation into elements; 3—filter; 3₁ ÷ 3ₙ—comparison of elements of reports with filter parameters; 4₁ ÷ 4ₙ—reliability evaluation; 5—combining of data; R—information decision.

The filtration method consists of the following steps:
1) analysis of data within filter parameters;
2) determination of confirmations;
3) determination of weight coefficients;
4) combining of data;
5) comparison with threshold;
6) decision.

The analysis and confirmation determination steps are new ones. Analysis consists in singling out information related to filter parameters. The difficulty here is to avoid discarding indirect data. The results of this step are reduced to tabular form.

The next step involves working out the table. A new table is constructed, whereby the lines contain—as before—the characteristics, but the data in the columns are rearranged as follows: first come the columns of direct confirmation in which are entered data that directly confirm a characteristic. Then follow the columns of indirect confirmation and the
columns of direct and indirect deviation. Direct confirmation is denoted by the “+” sign, nonconfirmation is denoted by the “—” sign and indirect confirmation (deviation) is denoted by a number that characterizes confirmation. Zeros are written in the empty spaces of the table (no data on some filtration parameter). The resulting table is called a filter matrix. Then the information is combined, a weighted matrix of the characteristics is constructed and threshold comparison and decision making are done as before. Filtration may be done by the amalgamation method, in which case the filter parameters (with equal or unequal weights), would emerge as the “experts.”

It is clear from the above brief description that the filtration method presumes a valid selection of parameters and exact determination of their weights in a decision. This should be done ahead of time. This method, moreover, is more easily formulated than the others for computer operation.

Below is an example of the use of the filter method:

Let it be required to make one of the following decisions relative to the level of preparation of a group of officers:

1) the group has completely mastered the course;
2) the group assimilated the theoretical part of the course, but it needs laboratory practice;
3) the group needs additional theoretical training, but its practical ability is satisfactory;
4) the group did not learn some parts of the course, from either a theoretical or practical standpoint.
5) the majority of the group knows the course, but the minority is lagging behind in theory and practice.

The following characteristics of mastery of a course may be established on the basis of many years of experience (see Table 6):

<table>
<thead>
<tr>
<th>Number of characteristic</th>
<th>Filter parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Knowledge of formulas and ability to use them</td>
</tr>
<tr>
<td>2</td>
<td>Knowledge of limitations, assumptions, conditions and proofs</td>
</tr>
<tr>
<td>3</td>
<td>Clear understanding of physical meaning of phenomena</td>
</tr>
<tr>
<td>4</td>
<td>Knowledge of schematic diagrams</td>
</tr>
<tr>
<td>5</td>
<td>Knowledge of instrument control mechanisms and ability to use them</td>
</tr>
<tr>
<td>6</td>
<td>Knowledge of wiring diagram, arrangement of instruments and their interaction</td>
</tr>
<tr>
<td>7</td>
<td>Ability to make repairs</td>
</tr>
<tr>
<td>8</td>
<td>Mastery of military application</td>
</tr>
</tbody>
</table>
This list, of course, could be made longer. Let us assume that all characteristics pertain directly to a decision and their weights are equal to one; the characteristics of indirect confirmation are not provided.

The input information is represented as evaluations of parts of the course; these parts should be selected in accordance with *a priori* characteristics. We will note that we have only one source of information—the examination. We will establish the thresholds of decision making: if the average evaluation is greater than or equal to 4.5 the decision is positive; if the average evaluation is less than 4 it is negative; if the average evaluation is greater than 4 and less than 4.5 the decision falls in the realm of uncertainty.

Let us divide the group into the following four subgroups:
1) the subgroup with the highest grades in all parts of the course;
2) the subgroup with the highest grades in only the theoretical parts;
3) the subgroup with the highest grades in only the practical parts;
4) the subgroup with the lowest grades in all parts of the course.

The results are written in the following form (Table 7):

<table>
<thead>
<tr>
<th>Number of characteristic</th>
<th>1st subgroup</th>
<th>2nd subgroup</th>
<th>3rd subgroup</th>
<th>4th subgroup</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.7</td>
<td>4.8</td>
<td>4.6</td>
<td>3.6</td>
</tr>
<tr>
<td>2</td>
<td>4.8</td>
<td>4.9</td>
<td>4.3</td>
<td>3.2</td>
</tr>
<tr>
<td>3</td>
<td>4.7</td>
<td>4.7</td>
<td>4.6</td>
<td>3.6</td>
</tr>
<tr>
<td>4</td>
<td>4.8</td>
<td>4.7</td>
<td>4.4</td>
<td>3.8</td>
</tr>
<tr>
<td>5</td>
<td>4.9</td>
<td>4.4</td>
<td>4.7</td>
<td>4.4</td>
</tr>
<tr>
<td>6</td>
<td>4.7</td>
<td>3.8</td>
<td>4.9</td>
<td>3.2</td>
</tr>
<tr>
<td>7</td>
<td>4.6</td>
<td>4.2</td>
<td>4.6</td>
<td>3.9</td>
</tr>
<tr>
<td>8</td>
<td>4.7</td>
<td>4.6</td>
<td>4.7</td>
<td>3.4</td>
</tr>
<tr>
<td>For all characteristics</td>
<td>4.7</td>
<td>4.5</td>
<td>4.5</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Comparison with the threshold values yields results presented in Table 8, where the “+” sign indicates confirmation, the “−” sign indicates nonconfirmation and the “?” signifies uncertainty.

It is clear from the table that the first decision is confirmed for subgroups 1, 2 and 3, and the fourth decision for subgroup 4; the fifth decision is confirmed for all groups as a whole, in accordance with which “the majority mastered the course, but the minority lagged in theory and practice.” Since the second and third subgroups each have only two uncertain characteristics, it may be assumed that they fit into the decision

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1 Indirect indications may be, for example, knowledge of mathematics (point 2) and physical endurance (point 8).
as made. This is a simple example and the result simply illustrates the formality of the procedure.

4. Situation Recognition Method

A situation is defined as a set of events which unfold in time and in space and have certain consequences. It is assumed that these consequences can be formulated and are important. A situation consists of three parts: conditions, established at a given point in time, or status (of the enemy, his forces, conditions of combat operations), processes, which may occur in the future, and result or consequences. In any given initial state the processes of conversion to a different state may vary; the reasons for this are random or volitional factors that have no bearing on the initial state. The result may vary accordingly. A diagram of a situation is illustrated in Figure 9. Situation recognition is accomplished before the onset of the consequences, at the time of determination of status or somewhat later. Usually, the interesting situations are those in which a given condition and its process of change are characterized by clearly expressed indicators.

![Figure 9. Diagram of situation: 1—internal process, characterized by certain indices; 2—environment; 3—unfolding of process under influence of environment; 4—result of process on some temporal or spatial boundary; 5—future development of events.](image)

The fundamental property of a situation is its dynamic quality. The result is the consequence of status and process, and process may be influ-
enced by external factors. If a commander knows a situation he can take measures either to alter the process or to prevent counteracting forces from interfering in the development of the process; he can do everything possible to change the situation in the desired direction. The earlier a situation is recognized the better. To recognize a situation means to make a decision as to what a certain result will be based on information about conditions (status) and process. Reconnaissance information may be obtained on conditions (status), and both reconnaissance and a priori information may be available on the process. The earlier a decision is made the less reconnaissance information is available on the process of situation development. Therefore it is necessary to use a priori data based on previous experience. The earlier a decision is made the easier it is to influence a process, but also the easier it is to make a mistake. There does exist an optimal point in time for making an information decision.

The chief distinction of the situation recognition method is that it includes a process, i.e., a dynamic element. In the comparison and filtration methods the dynamic properties of a process were described by a group of indicators, i.e., statically, which is oversimplification.

Consider the following example: An inspection team (commission) checks an air division and must make an information decision concerning the level of combat training. The situation here consists of the status of combat training, its progress and the results which will be achieved, let us say, in 1 year. The following information is available: the results of the inspection (description of status), plans, and information on the progress of combat training obtained during the inspection, as well as the personal experience of the team members in this field. The inspection is usually done selectively in a limited time; it is to some extent subjective, and therefore the input information is incomplete and inaccurate. The outlook for the future and the true progress of combat training which may differ from what was planned, must be clear in order to be able to make a decision. In preparing a decision the commission must continue to work until sufficient information has been collected. If it turns out that actual progress in combat training is not leading to the desired result the commission may examine other variations of the process and find (recognize) those which produce the desired result. The question, i.e. what conclusions will be made and implemented, falls within the realm of organizational and operational decisions.

Situation recognition is a new branch of cybernetics; established terminology and voluminous literature are still lacking; individual publications are narrowly specialized in character. The most closely related field is pattern recognition, but there is a fundamental difference. First, a pattern is static and a situation is dynamic. Second, situation recognition always involves prediction, foresight, and extrapolation, which is usually not the case in pattern recognition. Third, pattern recognition presumes the existence of a classification system, and a basic finite alphabet of
patterns established by training. When a new pattern is shown it is necessary to decide to which class it belongs (or to decide that it does not belong to any class). There is no \textit{a priori} classification in situation recognition, since the number of possible situations is infinite, even though the results have a classification and a finite alphabet. Moreover, various situations may be similar and may even partially overlap in terms of the initial state and character of process. Expressed mathematically, many situations are \textit{continuous} (i.e., such that a third, intermediate situation can always be found between two others), while many patterns are \textit{never continuous}. This property of situations is a serious barrier to their recognition.

We will distinguish three types of situations: simple, complex and degenerate.

Simple situations are those which are classified beforehand and, consequently, whose characteristics are known. The alphabet of simple situations is finite; it is assumed to be completely known to a commander and his staff, even though it is constantly being supplemented during accumulation of experience.

Complex situations are those which contain new unknown elements, and which consequently do not fit into an alphabet. The number of complex situations is infinite. This does not mean, however, that a complex situation cannot be recognized. If new elements are found, their characteristics and influence on the future course of a process are established, and the result is determined, then a situation may be considered as having been recognized.

A degenerate complex situation (or simply a degenerate situation) is one which may be represented in the form of a sum (composition) of simple situations. Such situations at first glance contain characteristics of novelty, which after detailed analysis turn out to be the result of the combined effect of known characteristics. The number of degenerate situations is theoretically finite (since it depends on the number of combinations of the elements of simple situations). However, this number is so large that it is practically infinite.

The reader is cautioned against thinking that a simple situation is easily recognized, or that it is easy to become oriented and to operate within it. In the case at hand the term “simple” is devoid of any emotional coloration and expresses only the idea that a situation is included among \textit{previously known situations}. Indeed, a “simple” situation may turn out to be very difficult and hard to recognize; sometimes it is easier to recognize a complex situation than a simple one.

A tank attack, command and staff training and army inspection of independent activity may be considered simple situations; in any case such situations are listed among described and previously investigated ones. The dropping of the first atomic bomb on Hiroshima by an American pilot was without a doubt a complex situation; in all probability
complex situations should include the first use of napalm or sweep radio jamming. When preparing to make an information decision we never know ahead of time what situation we may have to encounter. Therefore the method should be sufficiently general and ensure recognition of any type of situation.

The procedure of recognition consists of the following steps (Figure 10):

1. Separation of information about the situation (i.e., about the conditions and their development) from the general flow of information.
2. Analysis of this information, separation of it into parts pertaining to various characteristics of the situation and process.
3. Determination of characteristics, i.e., reproduction of the situation and of its development process, on the basis of information obtained.
4. Forecasting, determination of possible consequences.
5. Determination of the reliability of the forecast and comparison of it with initial information, elimination of contradictions.
6. Compilation of a full description.
7. Decision.

Figure 10. Diagram of situation recognition: A—input data; 1—separation of information pertaining to situation; 2—analysis of information, separation of elements of situation; 3—reproduction of process, construction of model and determination of characteristics of model; 4—forecasting of process, determination of possible results; 5—determination of forecast reliability; 6—compilation of description of situation (i.e., of the process and outcome); 7—information decision making.

The first step is more technical in character, since it presumes the making of decisions or, in general, the carrying out of any irreversible operations. From the vast volume of information that continuously reaches the commander, it is necessary to separate that part which has no bearing on the stated problem. Since it is very important not to lose useful information redundancy is permissible in this stage. In any case all the information is assumed to be retained for some time and it may be referred to in future steps. However, it is important at the very outset to set aside the most important, most characteristic and most reliable information and to proceed from it. This saves time and conserves resources.

The reviewability of incoming information and the presentation of
this information in a form that is quickly and completely perceived, are very important for the successful completion of this step. The presentation of the data should be devoid of any bias, subjectivity and emotionality. The person or system responsible for analyzing the input data must obtain it in "pure" form, in precise objective presentation. It should be pointed out that any verbal description, no matter how carefully it was prepared, contains emotional elements. Linguistic coloration often stresses a certain part of the content, even contrary to the desire of the author. Precise speech is essential in order to minimize intentional or unintentional authorial interpretation, but it is hardly possible to eliminate it completely. This circumstance ascribes a special function to the first step of recognition: presentation of information in the language of numbers and facts. Opinions, considerations and conjecture (although this, too, is important information) must be stipulated: such and such person is of the following opinion—and nothing more. Information about a situation must be stored in a form that permits easy access to it.

The second step, data analysis, is the logical continuation of the first step. The essence of analysis consists in systematization of information according to certain indices. Information pertaining to given objects, groups, persons, is extracted; the same applies to information pertaining to a given time, events, phenomena; to given targets, intentions, facts, etc.

The effectiveness of systematization depends on the ability to detect similarity, relationship, dependence. A report about a solar flare and a report about large shipments of fuel by the enemy to polar airfields do not seem related at first glance, but a good analysis will not miss the fact that solar activity is associated with fluctuations of the earth's magnetic field, an increase in the intensity of polar lights, and, as a consequence, a reduction in the reliability of radar. It is advantageous to initiate air actions under such conditions. Contradictory data, which are either rejected (if they do not seem to be of great significance), or are used (in accordance with reliability), depending on content, are extracted during analysis. Disinformation should also be excluded at this time.

Transition to the third step—determination of characteristics—is an important event. The same information may be the result of various properties of a situation, and transition to the characteristics may not be unambiguous. Ambiguity should be discovered, i.e., all characteristics which in principle may have effect on the information, should be established. Comparison of the characteristics should eliminate ambiguity. If complete elimination is not achieved, then it is necessary to examine several variations of the situation and, in this case, either postpone the final conclusions to the last step of recognition, or ascertain how incomplete the information is. It may turn out that some of the information has no explanation; we do not know what factors might have generated it. The presence of unexplained information is an indication of a complex situation. Such information should be subjected to additional analysis. It must be made certain that a complex situation does not
On this basis, some of the variations may either be discarded or reduced to a single variation. The initial information is evaluated one more time—

degenerate, i.e., that several simultaneously acting indications cannot be the reason for, or source of, incomprehensible information. If there is still confidence regarding the complexity of the situation, the information is forwarded for further processing in the next step.

The fourth step begins with the working out of hypotheses. The characteristics that were developed in the second step on the basis of data about the process of change in the situation are used as a forecast, taking into consideration the relations among the characteristics and possible consequences. The reliability of the forecast is attained by careful consideration of the mutual relations of the characteristics and processes; the limitations that make it possible to narrow the area of search and to achieve a specific result are derived from these relations. *A priori* data on military, sociological, psychological and physical processes, which take place during the unfolding of the situation, are very important. The correct sampling of *a priori* data in application to a specific situation is accomplished in the forecasting step.

Forecasting consists of two mutually opposing processes: the logical extension of events in their causal relationship and conjecture about the outcome, a *jump into the future*, in a certain sense a random sampling of possibilities, from which the return trip is made by a logical path, derived from the essence of the future. Thus, we do not have here the continuity that is always associated with mathematical extrapolation, but rather we are dealing with an "essentially discontinuous" process, which is based on strict causal continuity. Therein lies the dialectic essence of the fourth step. It is particularly characteristic of complex situations, where incomprehensive information is forwarded to the fourth step.

This information should be used in forecasting. The fact that we do not know how to connect this information with the present does not mean that it cannot be connected with the future. The degree of risk which it contributes, the range of the decision on which it may have an influence, the significance of the factors which it determines, etc., must be understood. This is the realm of dialectics and military intuition, which is the result of experience, talent and collective interaction.

Determination of the reliability of a forecast comprises the content of the fifth step, which is an element of feedback in the decision making cycle. Reliability evaluation should accompany all procedures at all steps. The fifth step is specific in the sense that a retrospective view can be taken from the standpoint of the formulated future, to see to what extent the results of each step are interrelated and to what extent the final result corresponds to the initial information. If there is discontinuity in the logic of discussions, which was difficult to disclose immediately, it may be determined when the representation of a situation (or, in any case, of the competing variations) is formulated to the fullest extent. On this basis, some of the variations may either be discarded or reduced to a single variation. The initial information is evaluated one more time—
in light of the formulated decision, i.e., in light of the interpretation given to the information.

The sixth step consists in writing a description of the situation, i.e., of the results of recognition. This description should be quantitative. A qualitative, declarative description has the same disadvantages as in the first step, but they are more perceptible here, since they may have a stronger effect on the final decision. The description includes the status (conditions), process by which it changes and the result. It is not a list of indices characterizing a particular element of the situation. Rather it is a detailed and purposeful (in the sense of the presumed outcome) presentation of all aspects and features of the situation with consideration given to the classification of factors and events and a clearcut delimitation of poorly substantiated assumptions. A formal description may take the form of a structural diagram; a network chart in which all events, transitions and their numerical (probability) characteristics are designated; a table accompanied by the necessary semantic and quantitative explanations, etc.

The seventh and concluding step is decision making. An information decision is made on the basis of the description of the situation and of all considerations that arose during the recognition process. A decision may consist in the confirmation of a single description, of one of the variations of situations, in refinement of the description, in the deviation of the variations and establishment of the need for additional reconnaissance. A feature of an information decision using the situation recognition method is that it treats the situation as an integral independent unit of decision, and not as individual characteristics and facts.

The completeness and integrity of information are essential for decision making. A decision concerning a situation is a high-order information decision involving serious operational or organizational consequences. In making a decision, however, the commander must proceed only from information at his disposal, and he must not become prejudiced under the pressure of responsibility.

We intentionally have not yet discussed volitional action. Volitional action may be taken at any step, depending on the content of the information and the importance of the decision.

5. Examples

The features of the various methods of preparing an information decision are best explained by way of examples. We will start with an imaginary situation, since imagination is a simplified model having great (compared with reality) clarity.

We will discuss events described by the American writers Fletcher Knebel and Charles W. Bailey II in the novel Seven Days in May. It is also a good illustration because it concerns sharp and instructive psychological collisions. All names in the novel are fictitious.
The action unfolds against the background of the "cold war." The director of the Joint Staff, Colonel Casey, becomes aware of several facts which are not clear to him; most of them are related to the personality of the Chairman of the Joint Chiefs of Staff General Scott, who is known for his far right-wing views and hostile attitude toward the Soviet Union. These are the facts: the secret formation of a 3,000 man communications security force ("site Y") under the command of an inveterate fascist, which is feverishly preparing to seize certain targets; information about the secret movement of units of this force; isolation of the Chief of Staff of the Navy, who is not invited to meetings of the Chiefs of Staff; an unexpected and illegal report by a right winger and enemy of the President concerning a Red Alert, during which time the President and Scott will be at an isolated command post; suspicious coded telegrams, etc. Casey suspects a military conspiracy on the part of the "hawks" to seize power and reports all the facts to President Jordan Lyman. There are no documented facts and Lyman decides to gather additional information, for which purpose he calls in his closest associates. The time to the alleged date of overthrow is short (1 week), and the participants in the events are faced with a complex situation. Most of them do not believe that a conspiracy is in progress, and the more farsighted ones (the President in particular) want irrefutable documented proof, since they consider risking personal prestige and national unity to be out of the question.

Leaving the political and military evaluation of the relations among the participants to the conscience of the authors, we turn to the question of how the data are analyzed and the information decision is made in the novel.

Colonel Casey is a typical West Point* graduate and Pentagon bureaucrat. He has combat experience, service know-how and firm convictions about the military position of the country, service relations and responsibilities. He analyzes the incoming information specifically from these points of view, using the filtration method. His filter is determined by his education, training, service position and recognition of duty. Passing the information through this filter, he discovers a discrepancy, combines the facts and reports everything to the President. Scott, who is Casey’s direct superior, has deceived him twice; Casey’s filter excludes deception in relations between military personnel and blocks all positive information about Scott in the future. Scott reported to one senator the top secret date of the Red Alert—the "filter" establishes the military misdemeanor. Other facts pass through the filter in like manner and in this light the movement of men from "site Y" to relay points of the national communications network indicates a direct attempt to capture these points for the purpose of isolating the government. It is interesting that no arguments can sway Casey: his “filter” is steadfast. Casey

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* Actually, according to the book, Colonel Casey was a graduate of the U.S. Naval Academy at Annapolis.
arrives at a ready-made information decision (military conspiracy against
the government).

Senator Clark, an ally of Lyman, also uses the filtration method, but
his “filter” is different. A shrewd politician posing as a patriot, Clark
helped Lyman greatly in the past and became a close friend. His criteria
are political, he has little military acumen and what is urgent and very
obvious to Casey is not perceived by Clark. Clark is incapable of ana-
lyzing facts from a military point of view, and Scott’s personal qualities
are unimportant—he has seen worse. Infringement on the prestige of
the government is not surprising to him, but the new military unit, kept
secret from the President and from the Senate Committee, is an accusa-
tion which may expose Scott, and Clark is sent to investigate. Clark’s
prejudiced political filter does not work well, and Clark, unaware of the
military aspect of the situation, finds himself in a preposterous position:
his is arrested by the very unit which he was sent to investigate. To him,
a United States Senator, such a possibility did not occur; he becomes a
victim of his own indiscretion, and only his reputation as “Georgia’s
best businessman” enables him to extricate himself.

The “wise and astute” Treasury Secretary Todd approaches the events
from a different point of view. A good administrator and businessman,
he displays from the start the greatest doubt in the direct interpretation
of the facts, but being convinced of the presence of danger he is prepared
to act with great decisiveness. He has no \textit{a priori} filter and he has no
intention of constructing one through theoretical deductions. Todd uses
the comparison method and analyzes each fact on this basis. Not one to
ignore trivial facts, he carefully weighs all “pros and cons.” Preoccupa-
tion with evaluation is alien to Todd’s sober mind and he is close to
mathematical formalism. Before he can arrive at the correct conclusion,
however, he needs more time, which in the unfolding situation increases
the danger.

President Jordan Lyman uses the situation recognition method. His
mentality is broader and he is capable of analyzing political, social and
military aspects of the events. Lyman has an attitude of condescending
good will toward his assistants; it was specifically these qualities he
expected of them when he assembled his working group. The President
analyzes the events in terms of the future and his influence on events
conforms with the future. Only he discerns a relationship between Scott’s
actions and the political activities of the right wing extremist MacPherson,
and to this he attaches great significance. Lyman essentially makes an
information decision before anyone else. He collects additional data for
preparing direct action against Scott, and not for reinforcing internal
conviction.

Scott’s private world is not opened up in the novel and we can judge
him only by his actions. Scott unquestionably uses the situation recog-
nition method. In spite of his great experience and high service rank,
however, he lacks Lyman’s depth. Lyman perceives the situation as
a complex one and acts accordingly. Scott considers it a simple situation, and therefore makes several mistakes, which lead to his downfall.

We have discussed only the chief factors that determined the thinking of the characters in the novel. The story, of course, is more complex and none of them uses just one method of arriving at an information decision. Casey probably was not even aware that he was using the filtration method, even though he had been building his “filter” all his life. In principle all the methods yielded approximately the same result. It is clear, however, that the recognition method works better than all the others in the specific situation.

Marshal of the Soviet Union K. A. Meretskov in the book Na službe narodu (In the Service of the People), gives a good example of a complex situation that cannot be recognized without additional information. The events described pertain to the campaign of 1940 against the Finns.

“The pill-boxes became more and more annoying. Try though we may, we could not knock them out, since the shells did not penetrate them. . . . I called a military engineer with a group of sappers and instructed them to penetrate into the enemy’s rear, blow-up a pill-box, see how it is made, and bring back a piece of concrete for analysis. We later sent this piece to Moscow. A scientific research institute did the analyses and reported: the cement is grade “600.”1

An information decision requiring such efforts consists of these words “the cement is grade 600.”

Complex decisions can be made with the aid of the comparison method at a higher level, whereas the filtration method or recognition method is used at lower levels. The characteristics of the filter should be known to the person making a comparison. An interesting example is a series of events that took place in the spring of 1943. The question of the summer campaign was being discussed and the Staff was collecting the opinions of military councils at the fronts.

Here is what General of the Army S. M. Shtemenko recalls:

“The military council of the Voronezh front did not hurry with proposals on the actions of our troops. But what was said in relation to the enemy was quite clear. . . .

“On the evening of 12 April, at a Staff meeting, everyone agreed as a result of careful analysis of the situation that the most probable goal of the German fascist summer offensive would be the encirclement and destruction of the main forces of the Central and Voronezh fronts on the Kursk salient. Action to follow the success on the eastern and southeastern fronts, including Moscow, was not excluded. I. V. Stalin displayed particular concern in this regard”2 (the italics are ours—V. D. and D. K.).

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1 K. A. Meretskov, Na službe narodu (In the Service of the People), Moscow, Politizdat, 1968, p. 185.
2 S. M. Shtemenko, General’nyy shtab v gody voyny (General Staff during the War Years), Moscow, Voyenizdat, 1968, pp. 152-153.
The above locations constitute an information decision even though the word “probably” is contained therein. The operational decisions that followed were derived specifically from it. It is noteworthy that the Staff made no decision concerning the time of initiation of the enemy offensive; information decisions of the fronts on this question were contradictory, additional analysis was inadequate, and therefore the Staff preferred not to manifest a “volitional factor” in this question, since the situation did not require it.

In many cases postponing an information decision in order to conduct additional reconnaissance cannot be tolerated. To stop the enemy advance on the Kursk salient, a powerful artillery counter-bombardment was prepared, which had to begin just before the enemy’s offensive, when he had brought up all his forces. But when would this take place? In the case at hand, the success of the most important operational decision was determined by an information decision: will the enemy launch his offensive on the dawn of 5 July 1943, or not?

Marshal of the Soviet Union G. K. Zhukov describes this occasion: “We learned that information obtained that day from a prisoner ... the enemy’s advance at daybreak on 5 July was verified ... The captured sapper reported on the preparedness of German forces for the offensive. The approximate time was 0300 hours, 5 July.

“K. K. Rokossovskiy asked me: ‘What should we do? Report to the Staff or order a counter-bombardment?’

“We have no time to lose, Konstantin Konstantinovich. Give the order ...”[1]

Considering the severity of the situation and the extreme importance of the information decision, the weight of the volitional factor must be considered very great.

The choice of method is a complex task; an unambiguous evaluation of the validity of the choice can be made essentially only after the problem is solved. Therefore it is essential to know all three methods and how to combine them.

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Chapter 4. Organizational Decisions

If there is no strong organization experienced in political conflict in any situation and in any period, then there can be no discussion of that systematic plan of action based on firm principles and steadfastly held to, which is the only kind that deserves to be called tactics.

V. I. Lenin

1. Structures

An organization is a group, intended for joint, goal-directed action: a combat group, educational institution, headquarters department, inspection team or athletic team. An organization may be created as a result of an organizational decision, but it also may spring forth spontaneously. Creation of an organization is aimed at a specific goal.

An organization consists of structure, orientation (location in space or in a territory) and distribution of functions among its elements. When making an organizational decision it is essential to consider several aspects related to the creation and subsequent functioning of a new organization, in particular its provisional characteristics (creation, structure, performance of a mission, existence), material capabilities (forces and resources), the stability of the organization, manageability, etc. During the preparation of an organizational decision the elements of a new organization are defined; they may be people, groups of people, units, unions, etc., depending on the stated goal. Technical equipment is also a subject of decision.

The foundation of any organization is its structure\(^1\), i.e., a relatively stable scheme of relationships among the elements. Structure is the most flexible and sensitive factor, alteration of which has a significant effect on the organization. For this reason we will first discuss certain general properties of structures.

It is customary to represent a structure as positions and the connections between them. Positions may be individual persons, organizations, command posts, military units, technical installations, etc.

\(^1\) Literally: building (Latin).
The basic forms of structure are:

1. **Linear** (Figure 11a). In linear structure each position (except for the end positions) is connected to two adjacent positions. Information passed from one end to the other becomes known to all. There are no relations in such a structure between command and subordination, and all connections are considered to be identical. If any connection is broken the linear structure is destroyed, since contact between the detached parts is impossible.

![Linear Structure](image1)

2. **Circular** (Figure 11b). This is a closed structure with identical connections. In this structure any two positions have two-way information exchange, which increases the data transmission speed and makes the structure more stable.

![Circular Structure](image2)

3. **Honeycomb** (Figure 11c). This is a complex structure with branched connections. In this structure there are many ways for information to travel, which ensures high reliability.

![Honeycomb Structure](image3)

4. **Multiconnection** (Figure 11d). This structure is based on the following principle: each position is connected to every other position. No one position has an advantage over another if the connections are equivalent. This structure affords maximum data transmission speed, since there is no need for detours. The reliability of such a structure is also maximum.

![Multiconnection Structure](image4)
5. **Wheel** (Figure 11e). This is a special case of an incomplete multiconnection structure, used very extensively and therefore deserving of independent investigation.

6. **Hierarchical** (Figure 11f). This structure has the most distinctly delineated command functions for some positions in relation to others. The lower positions are purely subordinate and the top one is purely command. The intermediate positions are both subordinate and command. The higher the level of the position the fewer connections it has.

7. **Star** (Figure 11g). This structure has a central position, which may perform command functions during operation, since all connections are closed on it. In the star structure the connections must also be command connections. This is a special, but unique and important case of hierarchical structure.

8. **A mixed structure** is formed by combining various structures or by replacing one of the positions with an integral structure of the same type.

When analyzing a complex structure it is sometimes helpful to substitute one position for a typical part of it. The result of this is a new simpler structure, but one whose elements have more complex functions. The quality of a decision and the time used in arriving at it may differ substantially for the various structures. Spontaneous reorganization, i.e., structural rearrangement, occurs in many cases when this facilitates a decision and when nothing stands in the way of it.

The properties of a structure may be characterized by the following generalized indices: operational capability, centralization, periphery, viability, volume of structure and entropy.

The **operational capability** of a structure is defined as its ability to react quickly to a change in a situation and external stimulation in accordance with its stated purpose. Operational capability depends on the arrangement of the structural elements and the distance between them, on the number of intermediate positions, and also on the general scheme by which the elements are connected. Operational capability is expressed numerically as follows: time of reaction to external stimulation (the probability that the structure will react within a given time), rate of intensification of the reaction to external stimulation. Operational capability depends on many structural features. If there are many connections and they are branched, then high operational capability should be expected, since the number of paths available for the transmission of information is high, but this is not always the case. Much depends on where the paths go and on the properties of the elements located in the paths of the information flows. It is important to know the price that is paid for operational capability. Let us assume that we have limited resources, part of which may be spent on the elements of a structure, and part on the connections between them. The more connections there
are and the more information they carry, the higher operational capability will be. But at the same time fewer resources remain for the formation of the elements of the structure. Therefore redundant operational capability, obtained at the expense of other properties of the functional elements, is not advisable. Too much operational capability is sometimes harmful; the structure reacts to weak stimuli, the control centers become overloaded and, moreover, they will interfere needlessly in the operation when peripheral elements could cope with the problem independently. An organization with such a structure will be oversensitive, or "nervous." The operational capability of a structure should correspond to the intended purpose of the organization.

Another important characteristic of structure is centralization, which determines the capacity of one of the positions to perform control functions. The centralization index can be expressed numerically as the average number of communication points (intervals) by the shortest route to the central position (Figure 11f). Other forms of description are also possible, for example: the relative number of elements that are linked to the central position; the number of elements which control all elements of the structure for a given number of intermediate points; average number of intermediate levels (points) to the central position. The higher this index, the more control over the structure and the less independence by individual elements and their groups. In the structure with similar (nonspecialized) elements there is no centralization (its index is zero), since there are no elements capable of performing control functions. The hierarchical structure is more centralized than the circular structure; the star structure, in which the behavior of each element depends entirely on the central position, has an even higher centralization index. It will be noted that the centralization of a wheel-type structure is less than that of a star structure, since the presence of peripheral lateral connections creates detours and improves the information position of peripheral elements. In the presence of peripheral connections the question arises as to what functions the central position is capable of accepting and which functions are delegated to it. In the star structure the functions of the central position are not limited and are not controlled by the structure. They may be limited in the wheel structure in view of the considerably greater capabilities of the peripheral elements, which may develop initiative, using connections that are independent of the central element. We intentionally used the term "capable of accepting" in relation to the central position. The expression "wants to accept" is sometimes even more appropriate. As soon as an organization is created it is given freedom of behavior, i.e., independence. Those functions which were first entrusted to individual elements need not necessarily be preserved; redistribution of functions may take place. It may turn out that functions develop which were not anticipated in the conception of the organization, and this leads to undesirable consequences.
When dealing with people it is impossible to give an irreproachable evaluation to all their individual characteristics and abilities. Therefore the operational capacity and purposefulness of an organization must be guaranteed structurally. If the structural elements are prone to self-instruction, development and specialization, then the functions of the elements will gradually be adapted to the structural capabilities. The centralization index is of tremendous importance in this sense. The structure stimulates specialization of the elements; in the star structure, for example, the central position sooner or later "seizes power." Such behavior is not the result of the particular qualities of the central element, but the natural reaction to external stimulation—natural behavior.

Centralization ensures harmony, but it restricts freedom of behavior and therefore prevents to some extent adaptation to a situation and sometimes education. For this reason the centralization index should be selected in strict accordance with a plan and the prospects for independent development, which is inherent to any organization, must be taken into consideration. Experience shows that an organization, created for a short time with a single, clearly defined purpose, should be centralized to the maximum possible extent. The question of multipurpose organizations is less clear. Caution is required here and additional resources should be expended to ensure structural flexibility.

The periphery index characterizes the spatial (territorial) properties of a structure, i.e., dislocation. The periphery index may be expressed numerically as the location of the center of gravity of the structure, i.e., as the relative number of elements and connections located beyond some boundary line. Weights may be ascribed to the elements and connections. The more elements there are concentrated on the periphery of the territory occupied by the structure, the higher the periphery index. This applies also to the location of the connecting lines. The circular structure, for example, may be purely peripheral if all its elements are located near the boundary of the territory and the connections also pass along the boundary. The star structure may have a high periphery index if the central position is located near the boundary. One periphery index cannot completely characterize dislocation. In many cases a structure either has no periphery index at all (headquarters structure, for example, if the location of the offices is ignored), or it is unstable (the structure of an air force, naval or armored unit may have a widely ranging periphery index). In other cases this index acquires a certain character (for example, the structure of a fortified region or of radio engineering forces). Structures with a high periphery index are usually also characterized by great autonomy. Such categories as front line length, depth of defense, bridgeheads, communications systems, etc., find their reflection and (very importantly) mathematical description in the properties of the structure.

The viability of a structure determines its ability to preserve the meaningfulness of other indices when part of the structure is destroyed. The
viability index may be a relative number of elements (connections), destruction of which would not cause the other indices to extend beyond permissible limits (the probability that the indices will not drop to the threshold value if a given number of elements is removed from the structure). The defensibility of the various elements is taken into consideration when determining the mathematical expression for the viability index. For example, the breakdown of the central element of a star structure entails its total destruction. However the central element is protected better than the others, and this fact should be taken into consideration. The factor of protection from internal conflicts is less clear: this is a non-structural factor which depends on the distribution of functions among the elements.

Of all the structural types examined above, the multiconnection structure has the greatest viability and the linear one has the least viability. Structural viability should not be equated to organizational viability; the latter also depends on the retention of the given functions by the elements. High structural viability, however, to a certain extent stimulates behavioral stability of the elements.

The next index is structural volume, which characterizes its quantitative composition. Depending on the specific purpose of an organization, this may be the number of elements (number of units), average territorial distribution density of the elements, etc. There is an optimum structural volume (as volume increases the functions of the elements break-up, but the number of connections increases), which is very sensitive to external conditions.

Up until now we have been discussing invariant deterministic properties of structure. Actual structures are variable and not all connections in them are used to an equal extent. A headquarters, for example, is built as a hierarchical structure, whereas direct communication among all officers permits the structure of the headquarters to be regarded as multiconnected. However the weight of direct communications lines is less than the weight of service lines. Therefore it is wise to introduce a probability measure for considering the stability and importance of communications: to each connection is ascribed a probability, expressing the frequency of utilization of the connections, and usefulness or weight during operation of the organization, or both. In such a description any structure may be considered multiconnected, in which some connections have zero probabilities. A structure in which only the probabilities 0, 1 are ascribed to the connections is called deterministic. A structure in which the probabilities 0, 1 are not ascribed to any connection (but only intermediate values) is called strictly probabilistic.

The most ordered structures are deterministic and the least ordered are structures in which equal probabilities other than one are ascribed to all connections.

Probabilistic weight may vary and depend on the properties of the
structural elements, distance between them, technical state of communications systems, time of day or year, situation, etc. In this case dispersion (or the law of distribution) must be examined.

The measure of disarray of a structure is **entropy** (similar by mathematical definition and conceptual sense to thermodynamic and information entropies, but not identical to them). Entropy is somewhat complex in numerical expression: taken with the opposite sign, it is proportional to the logarithm of the difference between the number “one” and a standardized (to the number of connections) sum of the products of probabilities of the connections for inverse probabilities. The entropy of a determined structure is equal to zero; such a structure is most viable and responsive, but it is also least inventive. When a structure his high entropy (up to a certain limit) the inventiveness of the organization increases, but viability and responsiveness decrease. For each task (class of problems) there is an optimal entropy, for which the organization has maximum effectiveness.

The above indices characterize various aspects of structure. By rearrangement it is possible to increase one index at the expense of the other. Let us assume that yet another level is added to an hierarchical structure. What will happen? The operational capability of the structure decreases, since an additional transmission stage appears in the chain of control. The viability of the structure decreases because of an increase in the number of vulnerable elements. Volume increases. By and large a comparatively minor change resulted in appreciable consequences.

The negative properties of a structure are manifested unexpectedly in complex situations and at the most inopportune time. One recalls the drawn out discussions before the war and their consequences with respect to the advisability of adding large tank forces to our army. The discussion that took place was not about the total number of tanks, but about the structure of the forces. In making an organizational decision, therefore, it is necessary that structure be quantitatively substantiated.

### 2. Distribution of Functions

Let us turn now to distribution of functions within an organization. This does not mean service functions (i.e., command, political, educational, technical, economic, etc.), but special functions of structural elements within the organization.

There are three such basic functions\(^1\): information function, management function and influence function (on the environment, on the enemy).

The information function is related to the collection, reception, collation, processing and transmission of information. Information functions include the collecting of reconnaissance data, ensuring communications

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\(^1\) The necessity and sufficiency of these functions have rigorous proofs.
between all links, the reporting and preparing of data for decision making, topographic and aerial photography, sociological analysis, etc. Instruction (but not education) is also an information function.

The management function includes analysis, recognition and evaluation of situations, working out and coordinating decisions, their optimization and monitoring the execution of decisions.

The influence function is any action related to active influence on other organizations, objects or any structural elements, especially combat activity.

Other complex functions may be constituted from the stated functions. A commander accomplishes all three types of functions: information, management and external influence. Training presumes the combining of the information and management functions.

Each structural element, from the standpoint of its functions in the organization, is considered to be an integral whole. For example, a tank army as a whole performs an influence function, but its headquarters performs a management function. By dismantling the structure of an organization step by step, we arrive at ever smaller subdivisions with smaller structural volume, but we never arrive at an element which in principle would be suitable for the performance of only one function. For each organization there is an optimal relation among the costs for elements of information, management and influence.

An organization is an integral, whole entity, independent to a certain extent. There is a dialectic relationship between structure and functional distribution, and also a dialectic contradiction; their mutual interaction under the influence of the external environment forces an organization to live its natural life in accordance with certain laws. The external properties of an organization have much in common with human qualities. This means an ability to adapt to external conditions, to exhibit behavioral stability, purposefulness, single-mindedness and even emotionalism. An organization has its own psychology, the expression of which is character.

Collective psychology is one area of science in which little work has been done, particularly in terms of practice. It may be assumed that future development of collective psychology will contribute much to an understanding of organizational decisions. A knowledge of psychology and character makes it possible to predict the behavior of an organization in any situation. Human psychology defines character as a system of attitudes and behavior. This definition may also be applied to an organization. Moreover, the qualities of organizations may be divided into the same types as for human beings. Steadfastness, endurance, persistence, will, etc., are inherent to organizations.

One may also speak of the “temperament of an organization” in the

same sense as human temperament. Temperament is defined as the most general characteristic of behavior. Temperaments are denoted through the following attributes: level of activity and performance, communicability, i.e., social contact, adaptability to changing conditions, level of emotions. The following classification of temperaments is used: choleric (high excitability, impulsiveness, impetuosity and cyclic in activity); sanguine (energetic, quick to lose interest, listless without work); phlegmatic (even tempered, steadfast, persistent, reserved, systematic but inert, immobile and adapts slowly to changing conditions); melancholy (emotional, introverted, reserved, but tactful and sensitive).

When analyzing the structure of character, psychologists distinguish in it several factors which, interacting with each other, form the dialectic integrity that is inherent to the human personality. Under certain conditions some qualities of character emerge and play the dominant role, and under other conditions these factors retreat, giving way to others. This also applies to organizations.

The following properties of character are distinguished (as applied to an organization):

1. **Strength of conviction.** Conviction, confidence in a certain idea (political, moral or technological) is a social factor. Strength of conviction is defined as stability and ability to survive despite the influence of external destructive forces, and also depth, i.e. significance from the standpoint of behavior and interaction with the environment. Communist convictions, for example, are the strongest factor behind the proper orientation in a situation, determining the entire behavior of man and organization. The strength of communist convictions is capable of surviving any test. Conviction in the validity of Copernicus' system may also be unswaying, but such a conviction is trivial for many organizations and has no effect on behavior in specific situations. Therefore it is important to determine the system of convictions that is directly related to the purpose of an organization and to evaluate its strength.

2. **The volitional factor.** Will is the determination of intentions and actions, independence, decisiveness and steadfastness in attaining a goal. An organization has a specific goal, from which derives purpose, and consequently it has a will. Will ensures steadfastness in accomplishing a goal and mobilization of forces up to and including self-transformation of the organization.

3. **The emotional factor.** An emotional attitude toward social life is a property of an organization. An organization may be comprised of people with different sympathies and antipathies, but during the process of joint operation a stable emotional attitude is formed toward that which is directly related to combined activity. An organization as a whole may not display any emotion toward the other aspects of life. The strongest emotions are a feeling of collective responsibility to the country,
a feeling of solidarity and mutual assistance, and a feeling of hostility
toward the enemy. These properties are intuitively distinguished and
understood, but they do not suffice for quantitative evaluation. We make
no attempt to judge whether such evaluation is possible given the con­
temporary state of human psychology, or whether it is necessary, but it
must be done for an organization. An organization consists of many
people, but its analysis is simpler in some respects. An organization has
a specific purpose, and this introduces certainty, which is so hard to
formulate for an individual person. In view of the fact that character
traits of individual persons very rarely coincide, specific traits tend to be
smoothed out. The character of an organization depends to a greater
extent on the structure and functional distribution than on the character
of people (responsible people), although they also play a definite role
(especially in hierarchical structures and in small organizations, where
smoothing out is not as great). The character of an organization may be
described by fewer indices, which are simultaneously less emotional and
intuitive, more objective and more easily measured. The character of an
organization depends to a great extent on the relationship between two
indices (not to be confused with the quality indices of structure!):
sensitivity and stability. Both indices are used in their precise definition:
sensitivity is the intensity of reaction to external information; stability is
defined as a steadiness in the face of external actions. These indices per­
mit deep penetration into the character of an organization.

In some cases structure is built on the basis of experience: experience
dictates the pattern from which to proceed. There is no guarantee, how­
ever, that experience is reliable in any specific case, or that the pattern
will work. Sometimes authoritative experience can be harmful. Shortly
before the Great Patriotic War, the question of developing large-caliber
mechanized artillery units was discussed. This, of course, required enor­
mous expenditures. A different opinion also existed: increase the num­
ber of artillery sub-units in the infantry. This corresponded to the
experience of the Civil War. It is now clear how far this experience was
from the problems of the day, but in 1938 there were serious vacilla­
tions. In general the tendency to “model the new on the pattern of the
old” is very strong and traditional, and it can hardly be overcome
by any way other than the substantiation of a scientific criterion capa­
ble of stating the exact range of applicability of experience. If the cri­
terion is formulated and is quantified, organizational decision making
becomes a mathematical problem.

3. Methods of Preparation

Three methods of preparing for an organizational decision are dis­
cussed: modeling, evolution and synthesis.

The modeling method (Figure 12) presumes that there exists some
pattern of organization, suitable for the purpose, or several fundamen­
Figure 12. Modeling of structure: 1—basic structure; 2—change of structure; 3—effectiveness evaluation; 4—cost analysis; 5—recommendation on new change or decision making.

tally different patterns. The patterns are analyzed: the structure (type of structure and quality indices) is determined; the distribution of functions is evaluated; sensitivity and stability are determined. A simplified description of the proposed new organization, its model, is formulated on the basis of these data. If the patterns are correctly chosen, then the model will be workable, but perhaps far from optimal. The model is the starting point for optimization, the basic decision which must be improved upon; here the basic structural and functional properties should not be altered substantially.

The improvement criterion is effectiveness or cost. One of them is the limiting criterion, depending on the initial data. For example, the permissible cost of organization is limited (from above) and consequently the structure is simplified by excluding certain elements. After each simplification, optimization is done in terms of effectiveness (for constant cost). The other version consists in placing a limitation (from below) on effectiveness; an organization is expanded to the required effectiveness level, and then it is optimized for the purpose of cutting costs (for a given effectiveness). The distinguishing feature of the method is the indispensable presence of a specific pattern, which is sufficiently close to the proposed organization in terms of properties. The initial model may be experimental, abstract or heuristic; its theoretical operational capability is important. This usually happens and that is why the modeling method has wide application. The need to develop organizations that differ radically from existing ones arises rarely, since any new organization must coexist and interact with old ones. Moreover, an organization consists of people with their personal experiences which must be used in the new organization. Therefore any new organization will retain continuity and will contain the features of former organizations. The entire problem consists in selecting the prospective properties of the organization. Therein lies the difficulty of the basic decision.

The development of large rocket engines and atomic weapons led to the creation of strategic weapons and strategic missile forces. The specific nature of the new service of the armed forces was exceedingly great: destructive power, deployment method, engineering level, personnel func-
tions, supply, military application—all of these were new and unusual. Nevertheless, many organizational forms retained their importance and were beneficial.

We are by no means talking about the possibility of absolute perfection in the organization of armed forces. However, the fact that these organizations are very similar in the various countries of the world is indication of the stability of organizational forms. Furthermore, changes should not be underestimated. When we are talking of long-term massive organizations, the creation and maintenance of which are very expensive, we must pay particular attention to the working out of all "trivia." Minor changes, which are not very expensive and are usually unimportant, may be very important under different conditions. The modeling method makes it possible to focus attention on the basic factors of an organization, to ensure their evaluation and careful development of the organization for a wide range of operating conditions. The modeling method is most suitable in cases when it is necessary to improve some aspect of an existing organization or to determine its range of application.

The evolution method is similar to the modeling method in that it presumes some initial basic organization, which serves as the starting point for the development of structure. In contrast to modeling, however, the initial organization in this case is constructed on different principles.

The use of the evolution method requires a description of the organization, a list of functions that the organization will be called upon to perform, and an idea of the essence of the relations among them. The main point here is the purpose of the organization and the character of its external relations. It is extremely important to distinguish purposefulness, i.e., the basic function derived from purpose, in the functional description. Since each new organization is created for a specific purpose, the writing of a description should be accompanied to some extent by clarification of purpose. The functional description need not be particularly complete and detailed. A functional description, of course, has nothing in common with a description of the functional distribution of the structural elements, about which we talked above. The basic structure is selected on the basis of the functional description.

The basic structure also need not contain a large number of elements; this makes the problem a little easier. The basic structure may consist of several elementary, unrelated structures. It is important that the functional problem be solved under specific conditions. Considering the small number of typical structures, the freedom of choice is limited here, so that the trial and error method is completely justified. Furthermore, as we will learn later, the choice of basic structure has considerably less effect on the final result than might seem at first glance. Suppose that a basic structure has been selected. The functions are distributed among
the elements of the basic structure in accordance with purpose. As a result a basic organization is created.

The purpose of the next step is to explain the range (conditions) of operational capability. In order to perform its function, each element of the basic organization must obtain the corresponding information, technical (or other) equipment and have the corresponding external contacts. What each element needs and the extent to which the requirements of the elements overlap must be established. This is determined on the basis of the content of each function and the relations between them, after which the structure is built upon with the corresponding elements. A new structure emerges, in which the functions of the elements, and consequently a new organization (first level organization) are again determined. The external elements of this organization also require support, which can be determined. Then partial optimization of the first-level organization is accomplished.

The essence of optimization consists in a rearrangement which permits the organization to take on a maximum number of functions from the total list without having to increase external support. This means that the structure of the first-level organization will be used to maximum benefit. Optimization is done by means of direct structural variations and distribution of functions. This entails the following: First the relations, then the functions, and finally the number of elements are changed. Since a first-level organization is small, its partial optimization can be expected to require few steps. As optimization progresses the content of functions to be performed should increase as a result of rearrangement of the organization. Evolution does consist of rearrangement. There may turn out to be two (or more) variations with functions that are similar in terms of importance and composition and with approximately the same support requirements. Such variations are competitive and may undergo a varying degree of further evolution. The variations are also subjected to external support. A first-level organization capable of remaining operational in the widest range of external support conditions is the most promising in the evolutionary sense.

After completing the optimization process, the structure is built-up, external support is reduced and a second-level organization is formed.

The second-level organization is also optimized. The process continues until the list of functions entrusted to the organization is exhausted and external support is reduced to the level stipulated by the initial restrictions. A general diagram of the process is seen in Figure 13. It is obvious from the diagram that the central features are changes or "mutations," related to a buildup of the structure. The purpose of these changes is to expand the capabilities of the organization in the most economical way. Experience shows that this method quite often consists in the development of a structure in accordance with a unitype design, i.e., by repeating certain types of structures (by multiplying the star structure,
for example, or building up the hierarchy). In this case the entire problem comes down to a correct choice of design, and since the design is contained in the basic structure, then the problem is one of selecting the best basic structure. A successful design is characterized by the fact that the process by which the capabilities of the organization (the number of functions performed) are expanded increases rapidly, more rapidly than for other designs. This is usually borne out in the early stages of evolution, which makes it possible to control the process and to replace the basic structure without losing a lot of time.

An organization with an asymmetric, aperiodic structure, in which there is no regularity, is comparatively rarely viable or functional. When external conditions change, such organizations usually lose some of their capabilities and are therefore short lived. The deeper reasons for symmetry and uniform structures in living nature are perhaps concealed in this fact.

The organization synthesis method (Figure 14) is the most universal one, but it requires complete initial data. The synthesis method uses computation to a greater extent than the other methods. The essence of this method consists in the construction of an optimal organization in conformity with a strictly formulated task and operating conditions. An organizational decision consists in the evaluation of this relationship.

Figure 13. Evolution of structure: 1—storage of structural fragments; 2—choice of basic structure; 3—plan of "mutation"; 4—mutation; 5—effectiveness evaluation; 6—cost analysis; 7—decision making.

Figure 14. Synthesis of structure: 1—storage of fragments of structure; 2—description of task; 3—composition of workable (redundant) structure; 4—effectiveness evaluation; 5—cost analysis; 6—optimization; 7—decision making.
and in the confirmation of the organization. Preparing for and making a decision by the synthesis method requires detailed formal description of the tasks of the organization. The writing of such a description poses serious difficulties, since very often not even the goal of a new organization can be precisely and uniquely formulated because the range of its activity is not completely clear. It is even harder to formulate conditions. Our notions about conditions are usually declarative, incomplete and disorganized; it becomes necessary to use such categories as “difficult operation conditions,” “numerous external contacts with many organizations,” “capability of flexible management,” etc. Even in cases when these categories are intuitively clear, they are difficult to formalize; the situation is even worse when various people have different concepts about the organization, or if the goals (in multipurpose organizations) have different and undefined importance. However, even in cases when there is no complete formal description, the synthesis method retains its importance. The fact is that probable limitation can be imposed on unknown and partially known parameters, or probable requirements can be imposed on them. This makes it possible to substantiate the optimal (for a narrow range of conditions) structure of an organization, which can be used as the basic structure, and by using the modeling or evolution method, to expand capabilities in the desired direction, even if this direction is not very well defined. The advantage of the synthesis method is that it theoretically gives the solution mathematically, so that it is devoid of the traditional and subjective tendencies, even thought these tendencies may appear in the description where they are easier to detect and eliminate.

Thus, the description of purpose, tasks and operating conditions of a proposed organization is written in the first stage of development. This description may be declarative (verbal) at first, but it should be as detailed as possible. It should be borne in mind that if any important aspect of organizational activity is not explained in the description, then it becomes impossible to introduce refinements in the future and the synthesized organization becomes unworkable.

A description must include the following basic points:

—goal of the organization;
—means of attaining the goal;
—on what means at the disposal of the organization the attainment of the goal depends;
—what external factors influence the attainment of the goal;
—what resources and factors pertaining to the organizations are interrelated and of what does this relationship consist;
—what must be determined during development of an organization;
—what limitations are imposed on the parameters of the organization.

The initial draft of the description may be general and approximate, but in the process of finalizing it, various details that come up should
be developed to the maximum possible extent. The verbal description is
then reworked into a mathematical one. Symbols are assigned to all
factors, parameters and indices.

The purpose of the organization is described mathematically by its
effectiveness. To substantiate this effectiveness and verify the equations
for computing it is the main problem when writing the description, and
future success depends upon the correct solution of this problem.

The most difficult problem here is determination of the goal attain­
ment criterion. Suppose that an organization must be created for defend­
ing a group of installations and a ready-made pattern cannot be used.
The purpose of the organization is the defense of installations. But what
does defense mean? It apparently means the preservation of the installa­
tions, hence the natural transition to averted damage. The degree to
which damage is averted may be used as the goal attainment criterion of
the organization. This criterion is a quantitative expression, is tied to the
parameters of the organization, to external conditions (air raid charac­
teristics), and also to random factors. The number of enemy airplanes
that are prevented from reaching the targets may be used as the criterion
(if, for example, we are discussing air defense), since this criterion is
uniquely related to averted damage. This, however, is not always correct.
Suppose that people must be protected and the problem consists simply
in getting the people into shelters before an air raid. This means that we
must warn personnel about an air raid as soon as possible and delay the
enemy for a certain amount of time. It is better here to use as the cri­
terion not the averted damage, but the time that the organization makes
available for sheltering the people. The averted damage over a certain
period of time may also be used as the criterion. One must think very
carefully before choosing one of the criteria or changing it. The math­
etical expression for effectiveness is constructed on the basis of the
criterion; it is essential to establish its dependence on the parameters that
define the makeup of the group, deployment of its combat elements,
organization of management, and also on the parameters that define
the forces of the enemy, the method of combat actions, electronic coun­
termeasures, etc.

The writing of a description includes the development of a hierarchy
of indices characterizing the organization to varying degrees of detailed­
ness. If synthesis is begun on the basis of the most detailed data, then it
becomes necessary to operate with such an enormous number of mutually
related parameters that the problem becomes boundless and unsolvable.
It is therefore necessary, starting with the effectiveness criterion, to grad­
ually breakdown the indices until the description is exhausted. The
hierarchy of indices is a description of an organization to varying degrees
of detail (or, conversely, generality). This approach is characteristic for
analysis of large systems, and any organization is a large system. In
order that a system of indices be constructive, i.e., to have it provide
the solution for a problem, the following conditions must be satisfied:
— the group of indices of each level of the hierarchy must be complete and must uniquely define the organization at its level;
— the indices of one level must be independent;
— the indices of a higher level must be calculated through the indices of a lower level.

This is followed by the mathematical formulation of limitations. There are two types of limitations: on the limiting values of the indices and on the relations among the indices. Both forms of limitations are determined on the basis of technical, economic and military considerations. Examples of limitations of the first type are: “a group may not include more than 10 firing batteries”; “the number of people may not exceed 1,000”; “the number of subordinate units may not be less than 3 nor more than 6.” Limitations of the second type determine the relationship among several parameters, stipulated by technical or other factors. For example, the location of command posts and firing batteries must satisfy the condition of self-defense of the elements of the group, the required speed of the computers at the command post depends on the amount of incoming information, and the latter depends on the number of communication channels; the number of operational calculations depends on the capacity of the equipment. The dependence may be assigned by equations, graphs or tables. Parameters that have a numerical expression should be limited by the description or it should be stipulated that the limitations are not imposed. Parameters without a numerical expression should be accurately defined in terms of composition. If, for example, discussion concerns an air group, then the types of aircraft which may be included in the group must be stated; if discussion concerns the level and qualification of an agency requesting armament, the description must include the permissible ranks (military titles, time in grade) and specialization.

Thus, mathematical description of an organization consists of the following three parts:
— hierarchy of quality indices;
— limitations;
— description of operating conditions (“environment”) and their influence.

The initial description is a source of information for the second step—construction of the organization. In the second step the problem of synthesis is solved. Synthesis may be a multistep process. The starting point may be either structure or composition of the elements, depending on which one is better reflected in the description. This is not of fundamental importance, but a successful choice does save time.

Consider the first version of synthesis: let us assume that structure is used as the starting point. Then, as the origin we select a multiconnected structure as the most general and universal; any other structure may be
derived from it without risk of omitting any version. The number of
elements of a multiconnected structure is determined on the basis of the
limitations imposed on the structure (or on indices directly related to it).
From this point the process consists in conversion of the multiconnected
structure to the optimal structure. First of all, however, it is necessary
to ascribe to the elements of the multiconnected structure the functions
that are derived directly from effectiveness. A multiconnected structure
may be redundant, and then it must be made to correspond with the
actual tasks of the organization. This requires determination of the opti­
mal distribution of the flow of people, materiel, energy and information,
which must circulate within the structure. As a result of optimization we
determine the overloaded or underloaded structural connections. The
load threshold is determined and all connections that are not loaded to
the threshold are removed. Elements with insufficiently loaded connec­
tions are also deleted from the structure and their functions are either
omitted or are assigned to other elements. This involves some redistribu­
tion of load in the structure; the higher the established threshold, the
more important this redistribution becomes. Structural simplification
should result in a cost reduction (if this does not occur, then simplifica­
tion is meaningless). The threshold is selected such that a reduction of
effectiveness will fall within acceptable limits. The resulting organization
is a generalized representation of what we were required to find, i.e.,
the first step of synthesis. It is represented too roughly as enlarged posi­
tions, the internal structure of which requires further improvement. Then
the next (more detailed) level of indices is used. Each element of the
organization of the first step is represented as a multiconnected structure
with the same number of elements and functions (i.e., with the same
degree of detail), so that it is possible to calculate the second-level
indices. The numerical values of the second-level indices should provide
the prescribed effectiveness, but this can be achieved only for various
ratios between them. Optimization is accomplished (according to the
minimum cost criterion with effectiveness limited from below) by sim­
plifying the second-level multiconnected structures and redistributing the
functions. As a result of eliminating part of the connections and part of
the elements we obtain a representation of the organization in the second
step of synthesis. The cost of developing this organization will be lower
than that of the first step.

In our discussions we proceeded from the assumption that the cost
analysis method is known in each step of synthesis. This is not always
the case, and often it is necessary to develop an organization under
conditions when only the most general information is available on cost.
In this case synthesis is based on effectiveness. The superfluous struc­
tural connections and unimportant elements must be eliminated so that
after completion of all steps of synthesis the effectiveness will not be
less than the permissible value. After this the process consists in suc­
cessive breakdown of the organization in accordance with the indices of
the 3rd, 4th and higher (if there are any) levels of the hierarchy. The result is an organization that corresponds to the description.

The second version of synthesis differs in that the starting point is not structure, but a set of elements, whose purpose is determined in accordance with effectiveness. All factors that increase effectiveness should be reflected in this group of elements. At first the elements are not interrelated. Relations are established by assigning corresponding control and command functions to certain elements, and this must be evaluated. If the effectiveness is too low the organization must be improved.

Theoretically, organizations that are built on the basis of both versions (simplification of structure or breakdown into smaller units) should be quite similar.

Final adjustment of the organization is accomplished in the third step (for both versions of synthesis) and an organizational decision is made, which consists in approval of the final organization. The organizational decision is based on keeping the effectiveness of the organization within a certain, sufficiently wide range of conditions at permissible cost. If this is not achieved, the organization is not approved and the project is started over again at some step.

In practice the above-described methods of organizational decision making may be employed in combinations and each method may be accomplished with a varying degree of depth and diligence. The use of one of the methods in "pure" form is hardly recommended. A method should be chosen as a function of the specific problem, technical equipment and time period available to the commander and his staff. For example, one may start with synthesis and proceed at a certain step to evolution and complete the work by modeling. One may use the first two steps of synthesis and then do the third step of finalization of the organization by the evolution method.

Optimization plays an important role in the application of all three methods. One should not use this term simply in its exact mathematical definition. Optimization may include the random use of any especially sensitive index, speculative convergence on the best solution, speculation, and then mathematical check.

Though care in the performance of all operations that comprise a method is always desirable and yields good results, one must not juxtapose care and scrupulousness against such an important factor as time. Experience makes it possible to marshal efforts toward the basic part of the project. One must avoid a negligent attitude toward details and the consequences of actions.

Negligence in the preparation of organizational decisions is costly. Even minor, insignificant and therefore hard to detect errors may have an effect for many years to come, causing great harm; their elimination requires a great deal of time and effort. Therefore the temptation of simplicity should be weighed against rigorous technique, which is a reliable tool.
Chapter 5. Operational Decisions

Each soldier must know his maneuver.

A. Suvorov

1. The Problem

Operational decisions are related to the choice of the method of conduct, principally the method of combat operations. They are made on the basis of information about the enemy and a formulated objective. The unexpectedness of situations, the rapidity of their change, incomplete information, misinformation, shortage of time and abundance of factors that must be taken into consideration make operational decisions exceedingly complex, important and emotionally tense. The commander’s responsibility for a decision is not diminished under any circumstance. Commanders of the conflicting sides try to penetrate as deeply as possible into the enemy’s intentions and at the same time to leave him with a certain (as false as possible) impression about themselves. The one who does this best may emerge victorious in the gravest—and at first glance hopeless—situation. Each side potentially may formulate an infinite number of strategies for himself and for the enemy. The question arises here as to whether or not a timely, objective and rigorous choice of the best, or in any case “sufficiently good”, strategy is meaningful. One must learn how to wage war in order to know how to make an effective operational decision, and a commander studies this all his life. The idea, the inimitable method, the operational move that one day may lead to victory, are developed and nurtured for long years. It is rarely possible to use one and the same strategy twice, and the commander must have many combat strategies in his arsenal. Voluminous literature is devoted to the description and analysis of wars and battles, but there are very few works that are devoted to the method of arriving at the best operational decision. Every training program presumes the use of experience. However “... it is extremely dangerous to attempt to carry over methods of armed combat worked out during the Second World War into contemporary conditions without making some sort of changes...” An analogous situation has always prevailed. The methods

of armed warfare have changed with the conditions of warfare (political, social and geophysical), with the appearance of a new weapon or when known methods become stereotypes, incapable of performing their functions. Those who exhibited conservatism have gone down to defeat; the term "conservatism" here in no way means the endurance of military conceptions: one may be speaking of a year or even months. Marshal of the Soviet Union, G. K. Zhukov writes: "After the defeat of the enemy at Vitebsk-Bobruysk, the flank groups of our forces made considerable advances, posing a direct threat of surrounding the entire Belorussian group of the enemy's 'center' army. Observing and analyzing at that time the actions of the German forces and their main command in this operation, we frankly were somewhat surprised by their awkwardly erroneous maneuvers which doomed their forces to catastrophe."

The popular expression "to lead is to foresee" pertains more to the preparation of operational decisions than to any other realm of activity. The effectiveness of operational decisions depends to a greater extent than information and organizational decisions on imponderable emotional and political-moral factors. To this should be added the fact that moral factors are dynamic, have a variety of manifestations, are difficult to describe and even more difficult to connect with other, numerically displayable factors.

Any scientific statement of a problem requires objectivity in the description and methods of solution. For this reason maximum formalization, accessible only to mathematics, is advisable.

The probability statement, in which a decision (if one can be reached) will be in some sense the best one statistically, on the average after a large number of tries, offers some possibilities. The following forms of statistical statement of the problem of strategies are employed:

—The minimax strategies;
—The strategy of minimum mean risk;
—The strategy of tolerable risk.

The minimax strategy is oriented toward the strategy of the enemy which is most unfavorable to us. It is a guaranteed strategy, in which the outcome cannot be worse than intended, regardless of the enemy's strategy. The advantage of a minimax strategy consists in its guarantee: it may be better but not worse. If success of a higher-level organization is very critical for the success of a lower-level organization (for example, failure by even one lower-level organization to accomplish its mission leads to the destruction of the entire group) then the best strategy is a minimax strategy. It is by no means the best one in other situations. A dear price is paid for the guarantee. An effective minimax strategy may not exist if the enemy has at his disposal strategies in which the

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1 G. K. Zhukov, Vospominaniya i razmysleniya (Memoirs and Reflections), Moscow, Izdatel'stvo APN, 1969, p. 580.
required result cannot be achieved; this means that the worst case cannot be counted upon in view of inadequate resources.

The minimum mean risk strategy minimizes some value, characterizing the result of military actions (for example, the probability of failure, manpower losses or damage suffered), averaged with respect to all possible strategies of the enemy. This strategy is of importance in the organization of the combat actions of similar subunits, operating under similar conditions. Its advantage is its high average effectiveness. A minimum mean risk strategy is a standard strategy. It has the least initiative, however, and is therefore unsuitable in complex situations. At the first opportunity the enemy will take measures to deprive us of this strategy.

In the tolerable risk strategy, a comparatively high risk is admitted from the very outset and a move is sought in which success (effectiveness) will be maximum. Its chief disadvantage is the difficulty involved in the correct determination of the amount of tolerable risk. This difficulty is often addressed to the senior commander on the assumption that he has great wisdom. There is a certain amount of validity in this, but it does not diminish the difficulty.

When the discussion concerns general recommendations pertinent to the actions of a large number of military organizations, a statistical statement is wise. However, when recommendations based on statistics are addressed to the regimental commander, who leads his regiment into battle in a specific situation, he naturally accepts them with great caution and skepticism: he wants victory today, not merely to win an average of 60 battles out of 100. It must also be considered that the commander goes into battle knowing that regardless of the outcome there may be no second battle for him.

The disadvantage of any statistical method consists in the fact that as it embraces and uses that which is general and uniting, embodied in a large number of similar-type battles, it involves averaging, and in a given case it is reasonable to say that it involves a disregard for all that is different, specific and individual.

It is essential to acquire a more thorough understanding of the essence of a specific problem and to substantiate the decision making methods that are closest to the best examples of human thinking.

2. Heuristic Programs

In education, a program of conduct is formulated to observe how people solve problems and what element is common to all in the human approach to various problems.

Similar programs that lead to a solution (recursive algorithm), but for which there are no consistent rules of mathematical operations, are written for the computer; the result is not computed but is found by means of a directed search.

The proponents of the heuristic method, in particular Academician
V. M. Gushkov and his school, contend that by using the appropriate computers it is possible to analyze any complex form of creative activity by discovering the information processes upon which they are based and by programming the latter for recreation in the computer. Heuristic programs are based on experience and are capable of improvement, i.e. of instruction and self-instruction. Detailed reports of a human (group) problem solving process are made for the purpose of writing heuristic programs. A set of operations, similar to the one that man performs, is developed on the basis of these reports. This is a heuristic program for the computer. The validity of a program is determined on the basis of the actions of the computer. A system of nonautomatic and automatic "incentives" and "penalties" is introduced: certain elements of the program are stimulated in the case of the successful solution of a series of problems and, conversely, are deemphasized in the case of failure. This results in the instruction and self-instruction of the program. Then a series of problems is solved using incentives and penalties (preferably of a competitive character), so that the computer can "compete" with man or with another computer, operating by the same or by different programs. Improvement will be mutual; analysis of the process and of the results of competition leads to new ideas relative to the content of the heuristic program, as well as to practical human activity. Much optimism and great disillusionment have been encountered on the road to the development and mastery of heuristic programs. The optimism was engendered by the successes of specific programs, and the disillusionment by an inability to discover and use the technological principles of the versatility of thought. Man is presently considered to have at his disposal programs on a variety of levels. First level programs determine specific behavior. Second level programs reflect professional activity. Third level programs build up the lower programs. Fourth level programs ("analyzer" and "combiner") perform situation recognition and define specific structural limits, from which conversion can be made to third level programs.

Individual factors play a very important, and often a leading role in cases when human relations must be taken into consideration.

The simplest example by which one can trace this influence and at the same time graphically illustrate a heuristic program, is a program for a game called "0, 1". Two players call out the number 0 or 1. If the numbers coincide, one player loses. If they do not coincide, the other player loses. The game requires analysis of the enemy's strategy and working out of one's own strategy. During the game the computer uses the accumulated data for the purpose of determining the psychological tendency of one's partner. A simple

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1 A. Newel, T. S. Shaw and H. A. Simon. An article "Elements of a Theory of Human Problem Solving," Psychological Review, No. 3, 1958 (Somewhat different terminology is used in the article).
program insured the defeat of a player not familiar with the program by a score of 55 to 45. However, a player familiar with the program won over the computer by a large margin of 60 to 40. After analyzing this result C. Shannon developed a simpler program with a smaller memory, but with faster reaction to the behavior of the opponent. In a game with a person who knows the program and who uses the optimal strategy the computer loses by the devastating score of 75 to 25. However, in competition with a computer having the original program with the large memory, i.e. more “cunning”, but more “slow-witted”, the second program wins 55 to 45. The fact that a comparatively simple program can compete with man in a purely psychological game is indicative. The game, despite its simplicity, is an attractive object for research, since without analyzing the opponent it is impossible to formulate any logical rules that ensure an advantage; it is just as impossible to predict the outcome. A statistical formulation made before any data is accumulated about the opponent is meaningless, because the possibility of winning is based only on psychological analysis during the process of accumulation of experience. The program of the game is a simple one for the computer to execute; it is also easy for man to learn how to act strictly by the program, and the accuracy with which the program is executed is easily controlled. In principle, therefore, it is possible to make do without the computer; this is less illustrative from the standpoint of computer heuristics, but it is nonetheless interesting since man makes note of the course of the game and discovers the weaknesses of the program.

Experiments in this game were repeated in order to disclose new factors. Since the psychological aspect stands alone and is the deciding factor, natural desire arose to strengthen it, and in particular to introduce “attack” and “defense” strategies for each player. The scoring of the game was changed as follows: if both players chose 0 the first player gets 2 points; if both 1’s come up, the first player gets 1 point; in the 0,1 combination the second player gets 2 points; and in the 1,0 combination the second player gets 1 point. Thus the “attack” strategy is 0 for the first player: by presenting 0 he may win 2 points, but he may also lose 2. The strategy of attack that involves the greatest risk for the second player is 1.

This game was analyzed in the following variations: “man-man”, “man-computer” and “computer-computer” for two heuristic programs: with permanent and temporary memory, i.e. in the “cunning” and “fast” variations. The “man-man” game unfolds with great excitement. Both players display persistence and ingenuity and the game rarely ends in a draw. The personal qualities and temperaments of the players are clearly manifested. Some try to “abandon psychology”, steadfastly use the same strategy and usually lose.
Experience is very important: a person with 2 or 3 hours of "seniority" can beat newcomers by a score of 70 to 30. Then the advantage is lost and often goes to the other side. The game is a tiring one and requires concentration. Characterically, in a simultaneous game of chess and "0,1", vigilance decreases noticeably, this is probably related not so much to mental stress (when two players are engaged in a game of chess one player tires sooner but plays better) as it is to excitement or other factors. As an illustration the course of a game between two experienced players is illustrated in Figure 15. In a game with a computer program the person who does not know the program first loses by a score of 55 to 45. After analyzing the "cunning" program he wins by a score of 80 to 20, and after analyzing the "fast" program he wins by as much as 85 to 15. Man quickly evaluates time during which the computer accumulates information for changing strategy, takes this time into consideration and, by moving accordingly, gains the advantage. If a computer uses random selection of strategy and does not react to the opponent's moves, victory is insured by the "attack" strategy. But not all operators react with the same speed: adaptation requires anywhere from 5 to 20 games. Very few people can unravel the computer program on the basis of the results of a game.

Figure 15. The course of a "0, 1" psychological game. The "man-man" version (the 1st player wins).
A typical "man-computer" game is illustrated in Figure 16. A "computer-computer" game with the identical programs unfolds with varying success and ends in a draw. When different programs are used the advantage of a "quick grasp" is displayed just as strongly as in C. Shannon's experiment, or even more strongly. The game is illustrated in Figure 17.

![Figure 16. The course of a psychological game of "0, 1." The "man-machine" version (machine wins).](image)

More serious considerations are involved in analysis of a program of military competition, described below. There is an objective, whose approaches are defended by a ringed system having a certain radius of destruction (Figure 18). The mission of one side is to penetrate to the objective and to inflict damage, and the task of the other side is to defend the objective. The composition and characteristics of the offensive and defensive systems are known. Arbitrary definitions may be assigned to "offensive and defensive systems": individual soldiers, divisions, aircraft, tanks, artillery. The criterion of effectiveness (price of competition) is the damage inflicted upon the objective, which is considered to be proportional to the number of offensive systems that penetrate the defense; the price is the same for both sides with respect to magnitude and is opposite with respect to sign. The probability of destruction of offensive systems that penetrate the defense depends on basic factors, as follows:
Figure 17. The course of psychological game of "0, 1." The "computer-computer" version (draw).

Figure 18. Diagram of a war game for a heuristic program.
Increases as overlapping of the zones of destruction increases;
Increases as the distance to the center of the zone of destruction decreases;
Decreases as the curve of the route inside the zone of destruction increases;
Decreases as the number of offensive systems simultaneously located in the same zone of destruction increases.

If the probability of destruction reaches a given threshold an offensive system is considered to be destroyed. The strategies of the attacking side are concentration of forces and maneuvering. The strategies of the defending side consist of concentrating their forces. The methods by which the strategies are determined are presumed to be known to both sides, but the specific program, and consequently the specific way in which forces are grouped, is not known. The conflict between the sides may be regarded as a game. The game may be solved by methods of statistical decisions theory without consideration of psychology.

A minimax statement (for some ratio of forces) will give a solution in mixed strategies. The attacking side is recommended to use concentrated breakthrough in one direction in 40% of the cases and breakthrough in 2 or 3 directions in 60% of the cases. The defending side is recommended to deploy its forces uniformly within the zone of defense in 35% of the cases and to concentrate them near its inner boundary in 65% of the cases. The decision in terms of minimum mean risk calls for a concentrated attack on the objective from a random direction and uniform distribution of forces in the zone of defense. In this case the averted damage is insignificant; the attacking side essentially always wins. Maneuvering is not advantageous to the attacking side and the concentration of forces in sectors is not advantageous to the defending side.

An heuristic program is essentially constructed on the same principle for both sides. The tendencies of the enemy are determined on the basis of experience, which is accumulated in games. The program is stimulated by “incentives” and “penalties” by changing the weight of the parameters on which the choice of strategy is based.

The program consists of two basic parts: prediction of situations and choice of strategies (Figure 19). Each part contains algorithmic (computational) elements, which evaluate the effectiveness of various strategies, and heuristic elements, in which the simplified and generalized conduct of the experienced operator is reproduced. The subprogram for selecting strategies is the most complex one. The fact is that the operator can neither satisfactorily describe his behavior (careful observation of the operator’s actions is useful to some extent) nor, very frequently, explain the reason for success or failure, which complicates the development of a system of incentives and penalties. An external analysis is useless in this case, since no one can determine in which intuitive assumptions the operator erred, because the operator himself does not know.
This limitation does not enable the program to accumulate experience in the required volume. The program, as executed by the computer, is extremely simple for such a complicated problem. Nevertheless, the results of its operation cannot be considered trivial.

Let us consider some results of the following types of events: “man-man”, “man-computer”, “computer-man”, “computer-computer”. The attacking side is designated as the first side. Turns are taken, as follows: Each player submits his version of the solution. The versions are compared and the losses are determined. The result is announced to the players, after which they prepare the next version. Preparation time is practically unlimited. There is one mandatory condition: the operator does not know who his partner is (man or computer), and arrives at decisions on the basis of experience only. “Man-man” event is the starting point for accumulating heuristic data and for analyzing the results. The ratio of the forces of the attacking and defending sides should be selected such that the average results of competition is a draw. The battle unfolds vigorously and is packed with dramatic moments in spite of this equalizing condition. The ratio of the loss inflicted upon the objective (consequently of the victory of the attacking side and loss of the defender) is dependent on the number of tries, as depicted in Figure 20a. The large jumps correspond to the changes of strategies. At the beginning of the conflict large jumps occur in nearly every try but after awhile they occur rarely while the magnitude of a jump increases, but eventually the jumps again level off. The smoothed (broken) curve is nearly periodic and has an increasing period, with an amplitude that increases at first, and then diminishes. The psychological causes that are embodied in this curve are not completely clear. It may be assumed that at first the opponents are becoming accustomed to each other, with the result that the mutual actions are predicted with greater accuracy, but then this
is perceived and they change their behavior. Complete mutual understanding is not achieved.

The strategies employed by the opposing players are repeated and experiences may be grouped. Strategies of heavy concentration of forces (such a strategy is nothing more than a trap, the use of which involves great risk) and uniform distribution of forces (the most cautious strategy) are especially characteristic. The attacking side uses the first strategy in the ratio of 70:30, and the defending side uses his first strategy in the ratio of 40:60. The dependence of damage on strategy (Figure 20b) shows that traps are preferable to cautious conduct for the attacking side. An exceedingly cautious strategy is also ill-advised for the
defending side: it is easily defeated by the enemy’s traps. However, it is not wise to employ the average optimal concentration of forces, since it is unstable and depends on subjective qualities of the players participating in a series of games, on which averaging was based. The use of traps is conducive to great gains and losses for both sides. This is illustrated in Figure 20c, where the dispersion of damage is dependent on strategy. Most operators are inclined to gamble. Another interesting feature is the dependence of the time (Figure 20d) the operator spends in analyzing the enemy’s strategy, on fluctuations of damage. This function shows that long-term psychological preparation is usually associated with a perceptible result; this is not surprising if one ignores the rather stable maximum of the deviation of damage from the mean value for a given optimum period; the latter is difficult to explain.

Man has a decided advantage in “man-computer” competition; man wins by a score of 70:30 with the ratio of forces that insures a draw in man-man competition. The dependence of loss on the number of tries is shown in Figure 21a. In contrast to the curve in Figure 20a, large jumps occur more often due to a change of attack strategies chosen by the operator when playing with the computer. The computer changes defense strategies more slowly; when man rapidly changes strategies, the computer selects them irrelevently more often than does man. The smooth curve also shows a period which is more regular than in the preceding case. It can hardly be said that the computer adapts to the opponent less well than does man; the computer exhibits fewer external manifestations of risk. Figure 21b illustrates the same tendency as in the preceding event, though it is less pronounced. The dependence of damage dispersion on strategy is illustrated in Figure 21c. As in the preceding case the strategy of concentration of attacking forces is associated with increased gain, but less so than previously, since the computer employs the dispersal of forces more “willingly.” The dependence of the period of damage change on its fluctuations, shown in Figure 21d, reveals to some extent the unique behavior of the computer. The computer changes its strategy very little if damage does not exceed 0.6, and very sharply as damage increases; the curve has a maximum. The overwhelming majority of operators (more than 90%) quickly establish that they are playing with a computer program. It should be pointed out that a computer conducts itself with considerable initiative.

Computer-man competition unfolds quite differently. The computer quickly arrives at the conclusion that the absence of a pattern is the better course of action for it. The dependence of damage on the number of tries is shown in Figure 22a. This curve is unique, since it has a set of large jumps, the number of which continuously increases. The period changes sharply in the smoothed curve. Dependence of loss on strategy, shown in Figure 22b, illustrates the advantage of concentrating forces, i.e. of using traps, by both sides. The dependence of damage
dispersion on strategy (Figure 22c) differs little from the previous case and does not contain important information. The curve in Figure 22d, illustrating the dependence of the period of damage change on its fluctuations relative to the mean, exhibits the opposite tendency with respect to the previous cases: a sharp change of loss follows a short period of "psychological" preparation. It would be rash to consider this fact an expression of "disorganization" in the actions of the computer: in the preceding case, after all, the computer conducted itself quite differently when that was advantageous for it. Such computer psychology, perhaps elementary from the human point of view, is completely independent and stable. Most interesting is the fact that the operator is
practically incapable of beating the computer: the score fluctuates at a given level with a slight advantage to one side or the other. Only 70% of all operators can correctly determine that they are competing with an automatic program.

Consider the computer-computer version of competition. After a brief period of establishing the mode of the game (there are fewer jumps here) events unfold more quietly (Figure 23a), although each side exhibits initiative. Nor is there the characteristic advantage in the strategy of concentrating forces (Figure 23b), even though such strategies are employed by the players. Accordingly, fluctuations of damage depend little on strategies (Figure 23c). One might expect the period of accu-
mulation of experience to be independent of damage fluctuations, but this is not the case: Figure 23d shows that in this respect the computer completely imitates human tendencies. On the average the attacking side has the advantage and wins by a score of 55:45. This phenomenon is difficult to explain, since under equalized (in terms of the number of systems) conditions of competition for the operators, their replacement by computer at first glance should give the defending side the advantage. Computers gain the advantage alternately and try to keep it by frequent, but not very intensive, strategy changes.

The chief disadvantage of the examined programs consists in the fact that they are capable of making a decision only on the basis of previous experience, lacking any, even partial information about the course of a
current game (for example, about the extent of concentration of the enemy's forces without an indication of direction). In short, the sides acted without reconnaissance and this left a specific impression on their behavior. Unfortunately, setting up the experiment with a more complex program involves enormous difficulties. The chief difficulties consist in incomplete description of behavior, which is used as the foundation of the heuristic program, insufficient operational memory of the computer, and weak objective control of the psycho-physiological state of the human players.

There is, however, another aspect of the question. All known heuristic programs omit the emotional side of human behavior, which unquestionably plays a tremendous part in the decision making process. This deficiency can be only partially compensated by numerical evaluations, of which the computer is more capable. We shall return later to the question of the emotional factor.

Heuristic programming is limited by the capabilities of the group of operators that was used as a basis for writing the initial training program. The limits of self-training are tied to the initial limitations, which at some stage become an insurmountable barrier. The limitations and imperfection of heuristic programs gave rise to pessimism among certain researches. We do not share this pessimism. The method of interrogation and recording of events essentially cannot yield much, since the better man solves the problem, the deeper he penetrates into it and the more the factors of his personal activity escape attention. Required here are objective—but in any case, external—methods of disclosing limitations and the stimuli that are encountered during formulation of behavior. Indeed, man is guided by heuristics, developed by himself, by competent individuals and groups. The methods employed and the forms of armed warfare are also heuristics. In particular, while surrounding large military units, penetrating the enemy's strategic front, and breaking up the enemy's strategic front and subsequently destroying it were considered to be large scale heuristics in the last war, current military literature discusses massive nuclear missile attacks, high-speed maneuvers, defense in counterattacks, holding of basic regions, deployment of main military forces during the first minutes and hours of war.

The disclosure of limitations in the formulation of behavior and interaction of programs at the various levels should result in significant improvement of heuristic programs.

3. Evolutional Simulation

Let us consider another possibility that differs fundamentally from the preceding one, namely, evolutional self-improvement of programs through abrupt changes in the program and through mutations, similar to biological ones. An evolutional program retains that part of the program which copes best with a problem and discards insignificant and
interfering elements. At first a program is selected which consists of several subprograms. Each subprogram independently examines the problem and independently solves it. This presumes the availability of initial experimental material which is required for “putting into motion” the process of evolution. A system of penalties for an ineffectual solution is also introduced. Each subprogram may be in the work mode or in the test mode. The initial programs are called “parent” programs. A “descendant” comes from mutations, i.e. random one-time alteration of the “parent” subprogram. If the “descendant” solves the problem better than the “parent,” the “parent” is discarded. If the converse is true, the “descendant” is rejected and a new “descendant” is created by another mutation of the “parent.” The number of “penalties” exacted determines the viability of a subprogram: if a subprogram is penalized too often and lags in evolution behind the others, it is discarded. An evolutionary program is depicted schematically in Figure 24. If a voluminous initial program is available, a program may presumably be “extracted” through evolution, which considers previous experience to whatever degree is desired, and which is capable of self-improvement. There are no fundamental limitations here and the process of evolution may proceed quite rapidly.\(^1\) A formal system for evaluating the results, which guides the evolution of a program, cannot be considered sufficient stimulus for im-

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provement. Here, too, as before, we encounter the same fact: a computer program is adequate, perhaps, but it should not be expected to give outstanding solutions. An evolitional program is inferior to the heuristic one in this regard.

Evolutional simulation, however, has fewer initial limitations. This is bought at the price of a high specific weight of randomness. Furthermore an exact and sensitive criterion for evaluating each "descendant" is essential for an evolitional model. The criterion is fully determined by the initial concepts, which place a limit on the perfection of a program. Both approaches are essentially related by the solution method, from which they cannot deviate, either by self-instruction or by evolution.

Man often resorts to the evolitional method of decision making. The entire simulation process proceeds mentally. Many examples can be used for tracing the step-by-step evolution of an initial plan, very often simple in concept, to a new, original and detailed one. The process of evolution is influenced by additional information. E. Tarle contends that Napoleon did not work out detailed campaign plans ahead of time, but "... designated only... main specific goals... During the course of a campaign... daily and sometimes hourly he changed his dispositions, considering not only his intended goals, but the situation as well." Further: "Napoleon listened to all from whom he could hope to obtain good advice, but he himself made the decisions. 'The winner of the battle was not he who gave good advice, but he who accepted the responsibility for its implementation, and who ordered its implementation,' he would say. Among the many opinions which the commander-in-chief hears there is often only one correct one, but he must know how to recognize and implement it."

We shall return to the questions of collective activity in operational decision making; it is important to note here that an outside opinion may be a factor that directs evolution.

4. General Theory

We shall attempt to formulate rather rigorously the program of arriving at an operational decision. Several "sets of factors" are assumed to exist, which describe the problem:

1) Goals;
2) State of our forces;
3) State of the enemy's forces;
4) Rules by which the ratio of forces is determined;
5) Possible actions of our forces;
6) Possible enemy actions;

1 E. Tarle, Napoleon, Moscow, OGIZ, 1941.
7) Rules for evaluating the results of military actions, extent to which a goal is attained;

8) Limitations on the possible values of factors 1 through 7.

The concept of "goals" includes annihilation of the enemy, inflicting of losses, economy of forces, prevention of losses, holding of positions, etc.

The concept of "state" embodies the composition, equipment, dislocation, politico-moral state, etc. The total state of our forces and that of the enemy's forces comprise a number of situations.

The concept of "actions" includes advance, attack, marking time, defense, reconnaissance, etc.

In each specific problem, some factors are given and others are unknown. The problems may be subdivided, accordingly, into the following four types:

**Type One** (Figure 25). Known: a) rules for determining the ratio of
forces; b) rules for evaluating goal attainment. Given: a) state of our forces and state of enemy forces; b) goal of battle; c) limitations. Determine: optimum type of action for our forces.

**Type Two** (Figure 26). Known: a) rules for determining ratio of forces; b) rules for evaluating goal attainment. Given: a) state of our forces and state of enemy forces: b) type of action for our forces. Determine: outcome of battle.

**Type Three** (Figure 27). Known: a) rules for determining ratio of forces; b) rules for evaluating goal attainment. Given: a) state of our forces and state of enemy forces; b) limitations. Determine: a) optimum goal of battle; b) optimum type of action.

**Type Four** (Figure 28). Known: a) rules for determining ratio of forces; b) rules for evaluating goal attainment. Given: a) goal of battle; b) state of enemy forces; c) limitations. Determine: a) desirable state of our forces; b) optimum type of action for our forces.
Other versions may also be constructed, but it is easy to see that they have considerably less practical importance. The decision making process presumes a directed alteration of controllable factors within limitations. The direction is organized in such a way as to achieve the desired result in the shortest possible time. Literature on the general theory of problem solving\(^1\) describes the following methodological systems of solution:

1. **Transformation Method.** The problem is transformed to another, more familiar and solvable form. The result is a new and simpler problem, the solution of which facilitates the solution of the initial problem. This is done several times. Through consecutive transformations

and the solution of specific problems it is believed possible to solve the main problem.

2. **Method of Isolating Characteristics.** Each problem has a large number of characteristics, but not all of them have equal weight. At the same time, success depends on the choice of characteristics on which the decision-making system is based. Several variations are formulated for isolating those characteristics that are assumed to be important. Each variation makes it possible to state the problem differently and to examine it from a different point of view. In this way it is possible to approximate the solution.

3. **Decomposition Method.** The problem is broken down into subproblems, each of which should be simpler than the basic problem. Since the subproblems are mutually related in such a way that the solution of one of them influences the others, all problems should be solved simultaneously. In this way the basic problem is solved.

4. **Analogy Method.** A similar problem is synthesized, the solution
of which is known or may be found. The difference between the initial and the synthesized problems is determined. A transformation (operation) is constructed, which being applicable to one of the problems, decreases the differences between them. By strengthening the analogy, the solution of the basic problem is found. This method is close to simulation.

The methods described above do not encompass all capabilities of human intellect and the very approach to their substantiation is not sufficiently dialectic. Yet another method may be formulated on the basis of an analysis of conflicting situations and generalization of experience with respect to human behavior in a precarious situation.

5. **Problem Inversion Method.** An hypothesis about a possible (desired) result of solution is formulated and the path to this result is sought. If such a path cannot be found the hypothesis is considered wrong and the search is repeated. The problem solving process includes a *dialectic jump*: data are accumulated, a possible solution is selected, and then its correspondence to the initial data is determined.

Possible solution methods, of course, have by no means been exhausted, and everything outlined above is nothing more than an elementary outline. Development of the theory will unquestionably lead to the creation of new methods.

Let us examine the methods described above in greater detail. The first question that must be answered is whether it is possible to define and formalize these methods more completely in order to use computers or to work out rules for training people. We will attempt to set forth the order of operations in each method:

**The order of operations in the transformation method** may be the following:

1. "Translation" of the problem from natural language to formal language, on which the decision making system is based, i.e. formal description of the operation.

2. Selection of basic factors of the formal description; these characteristics should correspond to the essence of the problem and express its content.

3. Validation of some means of influencing the factors for the purpose of changing them; use of this method for determining the range in which the solution should be sought.

4. Reduction of the number of factors on the basis of the preceding transformation; narrowing of the range in which the solution is sought.

5. Writing a new formal description of the problem that is more concise, simple and accessible for solution.

The process is repeated again and again.

The number of steps and the time required for solving the problem depend on its complexity and on how successful the transformations were, particularly the third step. A key device is to change the method of operations.
Method of Isolating Characteristics. In isolating characteristics we thereby determine our attitude to the problem. Selecting basic characteristics constitutes an information decision. The order of operations is as follows:

2. Selection of basic characteristics of the problem and writing of a narrowed description of it.
3. Influence on the basic characteristics by means of some transformation.
4. Evaluation of the result and discarding of unsatisfactory characteristics.

We examine here the various information decisions on the assumption that the set of possible methods of operation was determined correctly.

In the decomposition method the starting point is breaking up of the initial problem into smaller units. Since each subproblem influences all others, it is essential to have a constant exchange of information among the systems that are solving the subproblems. In particular, the basic characteristics of the subproblems must be closely coordinated. The initial decomposition of the basic problem and coordination on the solution of the subproblems must be accomplished on a higher level. The method of decomposition may be used, in turn, for solving subproblems. The order of operations is:

1. Describing the problem.
2. Breaking up the problem into subproblems (decomposition) in accordance with the objective.
3. Determining the basic characteristics of the subproblems and reaching agreement on them at a corresponding coordination level.
4. Solving the subproblems.
5. Refining the initial problem.

The process is repeated until a solution is found. The difference between this method and the others consists in simplifying the initial problem by breaking it down into its component parts. Practical activity is based to a large extent on this method, but it should not be overestimated and exceptional importance should not be attached to it: complex, multiconnected problems do not submit well to decomposition, and as we have already stated, the solution of each subproblem without consideration of the relationship among them is doomed to failure.

The analogy method is customarily used in view of its universal application. Discussion of this decision-making system may be summarized as follows: "What is interfering with the solution? What happens if whatever is interfering is discarded?" The result of such discussion is a simplified problem, after whose solution a new question is asked: "Why
can the solution not be applied to the initial problem? How should the auxiliary problem be altered in order to approximate the initial problem?" The analogy method is recommended for solving mathematical problems and for proving Poya's theorems¹, inasmuch as he contributed many new ideas to the problem of analogies. However, the intuitive theorems of Poya, very valuable from the pedagogical point of view, are far from formalism. The program may be formulated in the following order:

1. Describe the problem.
2. Establish the similarities and differences with an analogous problem stored in the memory of the decision-making system.
3. Synthesize a new, simpler problem with maximum similarity to the initial problem.
4. Solve the new problem, analyze the results.
5. Write a new description of the initial problem, considering the results of the solution.

The next method—problem inversion—is not described in any literature with which we are familiar, therefore we shall describe it in detail. The problem inversion method is most intuitive in terms of statement, and its formalization involves the greatest difficulties. The first step is to select the ultimate desired result from the domain of possible results (determined by the goal, situation and limitations). The domain of possible results varies, depending on the type of problem. The domain of possible results for a Type Two problem, for example, where the result of combat action must be determined for other given conditions, is easier to evaluate than for a Type Three problem, where the goal and method of operations are unknown. An hierarchy of desired results is formulated. For example, for situations related to defense, the classification may be made on the basis of the sample illustrated in

![Diagram of defensive measures]

Figure 29. Example of classification of defensive measures.

¹ D. Poya, Matematika i pravdopodobnyye rassuizhdeniya (Mathematics and Probability Discussions), Moscow. Izd. inostr. lit., 1957.
Figure 29. Breakdown of the classes may be continued to any degree of detail. The first inversion of the problem may start with the goal of the problem. Since the goal is determined by the makeup and significance of the characteristics of a situation, quantitative analysis of the characteristics may be used as the starting point for selection. An element of randomness (fantasy) should be included in the program. The program should facilitate narrowing the range of search on the basis of refining the characteristics as a result of inversion. The order of operations of the program is as follows:

1. Describing the problem.
2. Inverting the problem.
3. Determining the characteristics and transformations required for achieving the desired result.
4. Determining the correspondence between the required and the actual characteristics and correspondence of transformations due to given limitations.
5. Refining the description of the problem.

Thus, the central point of the inversion method is predetermination of the result. The dialecticism of the method consists in a qualitative jump “to the desired” based on analysis of the specific weight of the characteristics of the problem.

It may be asserted on the basis of experience that formalization does not involve insuperable difficulties and that the writing of good programs is a question of time and effort. Also important is evaluation of the method that is most promising in terms of the solution of each specific problem. Various methods may be used for solving one and the same problem.

5. Games

Man (a group), computer, and both simultaneously may be used as the decision making system. The computer may be helpful in organizing and evaluating man’s efforts. Therefore the development of the formal methods described above is also beneficial for instruction. The problem is how to master the formal methods in order to use them in practical purposes. A method is not a recipe. In order to master a method it is essential to acquire a clear understanding of it, and this is achieved through experience. The process of studying operational art and strategy must include systematic analysis of examples on which instruction is based. A given combat operation must be analyzed from the standpoints of different methods. In disciplining and, to some extent, formalizing his thought process the commander (operator) must strive to view each problem within the framework of one of the methods and proceed to another method only after finding the solution (or when he is convinced that it cannot be found).

Consider the following problem. Suppose two hostile groups are preparing for combat actions; they arm themselves and increase their com-
bat readiness. The average increase in armament per unit of time is identical. This process is shown in Figure 30a. As shown by the graphs, the rate of increase depends on combat readiness: combat readiness can be increased at the cost of reducing the rate of arms delivery. Each side receives complete information about the enemy, but with a lag, which involves errors in the current evaluation. The sides may begin to act at any moment of time to destroy the enemy's weapons delivery systems and the arms themselves. In so doing, the attacking side uses up part of its arms, but then the enemy's buildup and number of weapons are reduced. The dependence of the change of buildup rate on actual expenditures of resources of the attacking side (for different combat readiness) is depicted in Figure 30b. The reduction in the time of combat readiness makes it possible to deliver a more concentrated blow with greater effect.

Figure 30. The relation of forces in a war game.
The corresponding dependence is shown in Figure 30c. Thus, the wait-and-see strategy is related to the following alternative: arm or increase combat readiness (at the cost of some reduction of the arms buildup rate) in such a way as to maintain the same level of strength. If there were no errors in the enemy’s evaluation then the problem would have a unique mathematical solution. Since one of the assumptions is equal initial resources, both sides, generally speaking, may behave identically. One strategy is to cease delivery of additional arms and divert all efforts to increasing combat readiness. But the true state of affairs of the opponent is unknown, and this injects uncertainty into the situation, which leads to conflict.

Let us assume that the sides have decided to guarantee themselves against surprise attacks and are inclined to believe that the enemy is building up arms as fast as possible during the information lag time. It is easy to see that this will lead to an arms buildup. If in this case one of the sides exhibits wisdom and more accurately evaluates the situation, then it may seize the advantage by increasing combat readiness. The guarantee turns out to be deceptive.

By assigning evaluation errors it is possible to arrive at a unique solution. But how does one assign the errors? This is a case that arises when the risk is too great. It must be remembered that the enemy may strike at any moment. Would it not be more advantageous to attack first? The attack strategy consists in determining the resource and distributing it among the weapons delivery systems and weapons themselves. Conversion from the wait-and-see strategy to the attack strategy is permissible only when a perceptible advantage can be gained.

The range of the problem may vary from the tactics of isolated small units, whose supply is under the control of the enemy, to strategy of large formations. It is worthwhile to examine human behavior in a specific example.

Human behavior was evaluated to a certain extent in a two-sided game with a moderator, who informed the players concerning the actions of the opponent, thereby introducing lag. The tested contingent consisted of persons with a good mathematical background, capable of quickly orienting themselves and performing calculations, but who were laymen in the military sense. For this reason the result in no way reflects operational ideology. The conduct of the players depended to a great extent on the scale of the game. On the small formation scale (the first version) 60% of the players either build up arms rapidly or attack; but if the game is played for a large formation (second version), 70% of the players conduct themselves cautiously.

In the first version, at the very outset 40% of the games follow the indicative law of arms buildup and only 5% of the participants tried to "deter" the opponent while limiting arms delivery. They all explained their behavior as an effort to attain maximum combat readiness. Twenty-five percent of the players attack as soon as the calculated casualties
suffered by the enemy reaches 50%. Sixty percent of the players tend to underestimate the enemy's strength.

In the second version, 10% of the players generally prefer to refrain from building up arms as long as the enemy does not explicitly exhibit the opposite tendency. In cases when lag was not introduced and the players were aware of this, half of the games were not concluded: no one attacked first. A rapid arms buildup took place in 30% of the games and concluded in an attack in only 10% of the games.

Subsequent analysis revealed that 70% of the players made quite close to optimum decisions. The unjustified risk that was manifested in the small scale game apparently can be attributed to psychological motives, which are related to symbolic personal participation in operations and prestige associated with this.

The test subjects became accustomed to analyzing the stated problem and to formulating a plan of decision with the aid of the general theory described above, which made it possible to draw certain conclusions. We omit a mathematical description of the problem; it poses no difficulty in the case at hand. Thus, we will assume that the initial description is given by the graphs shown in Figure 30.

We are dealing with a Type One problem, since the condition of the forces, the goal and limitations are given. We are required to determine the method of operation.

The method of transformations as the second step (after description) requires the choice of basic descriptive characteristics. In our case we may use the amount of arms and time of combat readiness as characteristics.

The third step consists in acting on the characteristics. An action may be formulated as follows: 1) do not alter the characteristics; 2) select the arms buildup rate on the basis of some assumption about the enemy (in this case the combat readiness time is determined uniquely); 3) choose the armament buildup rate on the basis of evaluation of the enemy with the consideration of possible error. An assumption about the enemy may consist in the fact that our own intentions are ascribed to him.

The fourth step is to reduce the permissible means of action. This may be done on the basis of the preceding step by discarding explicitly unsuitable means of conduct of each side.

In the fifth step a new, refined description of the problem is formulated. Refinement (and simplification) is achieved by narrowing the range of uncertainty. The solution cycle is repeated until a final conclusion is reached. This conclusion is adopted for implementation and remains in effect until new information about the enemy is received.

As we have already stated, the method of isolating characteristics also begins with a selection of basic characteristics of the problem. We will use the same initial characteristics as in the preceding method—the amount of arms and the combat readiness time. The third step, action
on the characteristics, also coincides. We will assume that we are not satisfied with the result in view of uncertainty. In the fourth step we may try to formulate a new description of the problem, assuming that the information about the enemy is correct. This introduces certainty, but also an element of risk, which should be eliminated in subsequent steps. The fifth step consists in selecting a new group of characteristics. We assume that a satisfactory characteristic is the arms buildup rate. After repeating the entire process of discussions we may still come up with an unsatisfactory result. We formulate new characteristics, such as the amount of weapons, an increase in the arms buildup rate, and combat readiness time. The solution will be considered correct when rational (i.e. capable of having an influence on a course of events) characteristics are examined.

Let us turn now to the decomposition method. Suppose that we consider the relation between the arms buildup rate and combat readiness at the coordination level. Then, in the second step, we choose the following subproblems: 1) evaluation of the enemy; 2) determination of an efficient arms buildup rate; 3) determination of an efficient level of combat readiness. In the third step, the choice of basic characteristics of the subproblems, we may use: for the first subproblem the amount of arms and combat readiness of the enemy, for the second our own amount of arms and arms buildup rate, and for the third the combat readiness time and its rate of change. Coordination of the first and second subproblems consists in matching the amount of arms in accordance with the goal; and of the second and third subproblems, in satisfying the relation between the combat readiness time and the arms buildup rate, shown in Figure 30a; of the first and third subproblems, in the choice of a reasonable (from the standpoint of the goal) combat readiness time. The fourth step is to solve the subproblems. The fifth step consists in reformulation of the initial problem with consideration of the solutions obtained in the preceding steps. For example, we may consider the costs of weapons suppressing arms delivery systems to be independent of the costs of destroying the enemy's weapons, and on this basis we may formulate a new decomposition. In the problem at hand the decomposition method offers greater freedom in the choice of points of view than the preceding methods, but this is by no means always the case.

The use of the analogy method requires a set of solved problems, from which an analogous problem is selected. Such problems may be: determination of the optimal wait-and-see strategy when statistical errors in evaluating the enemy are known, determination of ideal combat readiness, and optimal (in terms of inflicting the greatest loss) distribution of weapons of attack for given combat readiness probability characteristics, and so on. These are calculation problems, for which an exact solution can be found. The similarity and the difference in comparison with the initial problem can be established on the basis of characteristics, which
should be formulated. In the given case, the characteristics are the conditions and limitations of the problem: the presence and character of enemy evaluation errors, the effect of combat readiness, and the goal of the problem. As the first analogy we use the optimal wait-and-see strategy. Error statistics are known and combat readiness time is zero. The next step is to synthesize a new, more similar problem. We add to the analogous problem, a finite combat readiness time in accordance with Figure 30a. The analogy is strengthened. We solve the new problem by one of the methods examined above and find additional characteristics, not mentioned in the initial description. Then we may go on to the concluding step of the first solution cycle: formulation of a new, more accurate description of the initial problem.

The problem inversion method requires a preliminary formulation of a hierarchy of solutions, as in Figure 31. The classification may be developed formally and may include heuristic elements. The problem may be inverted by choosing a result that satisfies the goal. Determination of problem characteristics for the selected outcome is done the same way as in the preceding methods. The required conversion is accomplished by varying the characteristics, i.e. in the final analysis by changing the factors, such as shown in Figure 29. If the solution is not satisfactory a new description is written, from which the unsatisfactory classes are excluded, the remaining one are broken down and new ones are added. We will recall that the initial classification should include both desirable and undesirable results so that unwise actions (those that may lead to an undesirable outcome) may be discarded. The inversion procedure may also be repeated without changing classification. Analysis of the above example confirms the point of view that man is guided by methods which fit into one of the systematic schemes, and subjectivity is displayed in even a simple and inconsequential game.

Formalization of the various methods as they apply to operational

Figure 31. Possible outcomes of decisions.
problems of a given type and character will obviously have much in common: description (language), classification of characteristics, type of transformations, etc. This gives rise to optimism in relation to the possibility of simultaneous application of several methods, which makes it possible to compare the solutions and mutually stimulate the programs.

If intelligent behavior is viewed as a combination of the ability to predict the result of the use of a chosen strategy and to compare it with the goal, then it must be stated that the goal itself is not very well defined. Herein lies one of the problems that must be solved. The goal of a battle is usually formulated by a senior commander in terms that are completely understood, but not sufficient for a formal description. To the commander, whose purpose is to attack an enemy objective, the goal is quite clear, and therefore this problem may be completely formalized. However, we will put ourselves in the place of the commander, who engages in battle with an enemy having superiority in strength. We will assume that his goal is “to disengage himself from the battle and to break away from the enemy with minimum losses.” Obviously, a more specific goal cannot be required of the commander. Nevertheless, this goal may be perceived differently. For example, the following goal may be stated: retreat, inflicting some punishment upon the enemy, thereby averting pursuit; you may retreat without battle, leaving a rear guard which knows it must fight til death, and save the main forces at this cost. This is defining a goal and is to some extent a method of solving the problem. In practice the goal is always so closely connected with the problem that its perception varies to some extent, depending on the personal qualities of the commander, and this is taken into consideration when the order is given. Herein also lies an emotional aspect. Hatred for the enemy may sometimes have a greater influence than many years of experience. In principle there are no obvious reasons why emotion should not be taken into consideration in a formal description.

A precise definition of the goal may be included in the solution. A goal (if one is designated) is a limitation which should be satisfied. A new, more specific goal (goals) is sought along with the solution within the limitation. The methods of decomposition and problem inversion are considered to be more helpful than the other methods. The decomposition method requires coordination of the subproblems at a higher level; such coordination may consist in determination of the correspondence between the goal and the means. The problem inversion method contains the prerequisite of surprise, which accompanies creative search. Clarification of a goal, and choice of an original unexpected goal that can misinform and confuse the enemy, but at the same time not extend beyond the “space of permissible goals”, i.e. beyond the given limitations, require goal suitability evaluation criteria. The degree of goal attainment was used earlier as such a criterion, but now the goal itself is being sought. The criteria should be concise, unambiguous and “well-defined.”
Let us consider the volitional factor. Will may be exercised in any step for the purpose of terminating unpromising trends and simplifying future operations. But if there are no rigid restrictions on time and capabilities, the volitional factor is not always necessary and is sometimes undesirable. The volitional factor is essential, however, in the very last step, when the solution is validated.

In conclusion we will discuss an historical example of the use of the inversion method on a large scale. During the development of the plan of the summer campaign of 1944 the main problem was the choice of direction of the main attack. The enemy’s weak spot might have been sought (as so often in the past), but the situation called for a different action. General of the Army S. M. Shhtemenko writes: “. . . and so, where should the decisive blow be delivered? Up-to-date analyses of the unfolding strategic situation convinced us more and more that the success of the summer campaign of 1944 must be found in Belorussia and Western Ukraine. A great victory in this region would provide the shortest route for Soviet forces to the boundaries of most vital importance for the Third Reich. In addition the most favorable condition was developing for directing counteroffensives against the enemy in all other directions, especially to the South, where a strong grouping of our forces was ready for action.”

The dialectic idea, namely the shortest route by which to send Soviet forces to the required boundaries, was transformed into a specific decision, reflecting the order of operations in the summer campaign.

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1 S. M. Shhtemenko, *General’nyy shtab v gody voyny* (General Headquarters during the War Years), Moscow, Voyenizdat, 1968, p. 226.
Chapter 6. Collective Activity

Practical authority should be entrusted to one comrade who is known for his dedication, decisiveness, courage and ability to carry on his work and who has everyone's full confidence.

V. I. Lenin

1. Basic Features

One-man management [i.e. unity of command] is a fundamental principle on which the armed forces are built. One-man management is concomitant with the collective form of situation analysis and decision making.

V. I. Lenin repeatedly stressed the importance of one-man management.

V. I. Lenin considered at the same time that comprehensive and thorough situation evaluation, consideration of various factors and effective decision making, particularly within a limited time, can only be done collectively. "Collegiality is essential for decision making in a workers' and peasants' state." At the same time: "Collegiality should not go beyond the absolutely essential minimum... the irresponsibility that is concealed by references to the group is the most dangerous of evils..."1 "... A specific person is entirely responsible for carrying out a specific task."2

V. I. Lenin devoted particular attention to group contact and harmony in work: "... Only through complete familiarity among the members of a collegium, knowledge of shades of opinions and trust can the task be accomplished."3 V. I. Lenin referred in many works to questions concerning decision preparation and decision making, responsibility and control over implementation. On the basis of thorough sociological research, conducted at different times, V. I. Lenin contributed much to the development of military science, particularly on many aspects of organizing the armed forces.

Each military formation is a social organism, in which objective laws

2 V. I. Lenin, Poln. sobr. soch., Vol. 52, p. 23.
3 V. I. Lenin, Poln. sobr. soch., Vol. 40, p. 239.
are at work. The dialectic unity of one-man management in leadership and group activity in discussion insures effective troop management.

Certain difficulties are inherent both to individual and to collective activity. The following problems can be distinguished in individual activity. 

The Limit of Thought Capabilities of the Individual. An interesting experiment\(^1\) was made on a comparative evaluation of human intellectual capabilities. People of different age, occupation and educational level were given tests (questions and problems), not requiring special training. Scores were awarded on the basis of a set of results. The results are presented in simplified form in Figure 32. "Relative intelligence", computed on the basis of the scores, is plotted on the abscissa axis, and frequency (the relative number of persons scoring the same number of points) is plotted on the ordinate axis. It turns out that given an unlimited test time the difference between the ability of the various persons to solve a problem is not so great: the difference from the average level (which should also be related to some extent to preparation and emotional factors) does not exceed 30–40%. Cases of exceptional intellectual prowess are discarded. When the test time is limited there is a wider distribution and the average number of points decreases by more than 30%.

![Figure 32. Comparative evaluation of mental capacities.](image)

A problem of battalion size exceeds the most complex tests by five to ten times with respect to the amount of information. It may be said with complete justification that many military problems, especially large scale ones, require collective analysis.

Slowness of the Process of Perception of Information and Thinking. Evolution developed a certain speed of thought, optimal from the standpoint of day to day life. Social and professional education improves perception and orientation, and develops abstract thought and speed of comparative analysis. Human nature enables man to adapt quite quickly to an unexpected situation, but it fails in cases requiring complex computations. The physiological limits of the speed of thinking remain low.

Man is capable of receiving not more than 100 binary units of mental information per second, and conversation takes place at the rate of 30 binary units per second. In calculations man can process 20–30 bits of information per second. There are examples of phenomenal rates of mental calculation (up to 200 elementary operations per second), but persons possessing such capabilities rarely combine them with the ability to quickly become oriented in a situation. Other than the rarest phenomena, there are no real capabilities and promises for significant improvement in the speed of thinking.

Subjectivity of Individual Thinking. Military and routine situations are described by such a large number of characteristics that it is impossible to take all of them into consideration. For this reason factorization, the disclosure of several basic, determining characteristics, is employed. Individual factorization is nearly always subjective. One of the basic reasons for this is the physiological property of preferences: man tends to overestimate great chances for success and to underestimate small, or ascribes too much specific weight to factors which he considers to be important, and decreases the specific weight of factors which he considers to be secondary. Subjectivity is to a certain extent a quality of all people without exception, and the less time there is for thinking, the more strongly subjectivity is manifested. Subjective perception of a situation entails subjectivity in decision making. The direct result is stereotyping of decisions, the customary means of behavior. Elimination of subjectivity under the influence of external information is a rare phenomenon. Human nature is such that the method used for processing informations is carefully insulated from external influence. Therein lies the dialectics of interaction with the outside world.

" Adaptive conformity" is an undesirable phenomenon in social psychology. When forming an opinion (plan of decision) man considers (sometimes subconsciously) the pressure of public opinion or of the opinion of certain persons on whom he depends. Even in cases when a problem is not a very serious one, it takes great courage and independence to propose an unpopular decision. This is not so much because of the fear of failure and sanctions, as emotional suppression of alternatives which do not correspond to generally accepted views. Sometimes the information that stimulates thought in a different direction is distorted and discarded. Previous failures and problems related to unpopular actions and opinions strengthen adaptive tendencies and give rise to uncertainty and new failures. Manifestations of adaptive conformity are particularly dangerous when it takes on a group character.

An alternative is voluntarism, refusal to consider either objective laws or any opinion whatever. The psychological tendency of voluntarism is to act contrary to laws, rules and opinions, and in most cases without the subject recognizing it. Adaptive conformity and voluntarism are two sides of the same coin. Characteristically, under the right conditions
they may be displayed by the same morally and mentally unstable persons, depending on their position, power and degree of control. Such persons invariably perceive on themselves the invisible fantastic "Shekli Medallion"—a device for measuring owners' pretentiousness. When the sum of pretentions exceeds a critical value the medallion explodes.\(^1\)

The above-enumerated deficiencies of individual activity are significantly alleviated and sometimes completely eliminated in group activity. Readjustment takes place in collective work. Receptivity increases, reaction is strengthened and self-criticism increases under the influence of group control. The most important human social features are manifested in all of this.

* A group has potent stimulating effect. Influencing the thoughts and feelings of the individual, the group can become the "triggering mechanism" for an "avalanche" of thoughts and direct the "avalanche" into the required channel. This circumstance is of no mean importance. The organization of thinking in a certain direction requires continuous will-power, which cannot be done with the same ease for all forms of activity. Scientists, for whom effective self-organization and self-scrutiny of thought is a professional requirement, are most capable of this. However this comes at a price and often leads to a weakening of behavioral control. An individual who uses much of his willpower for managing people must first control his own behavior, and is not always able to maintain the required intermobility of thought for a long period of time: there are too many distractions. A group provides psychologically natural constraint, helps to keep the thinking process in motion within intelligent limits, and eliminates both conformity and voluntarism.

* High Erudition of a Group. Saturation with diverse technology and large numbers of specialists in various fields demand of supervisors a broad specialization. One man, regardless of his educational level, cannot master at the required level all fields of knowledge, from mechanics to sociology. At the same time such knowledge is essential for arriving at an important operational decision. Consultations offer little help in the formulation of the basic idea of a decision, but this passive form of cooperation plays its own role in the evaluation of an idea. The supervisor cannot be a specialist of identical high caliber in each discipline. He is in no condition to include in his thinking process information that he does not understand and he is not always able to formulate a special question so as to obtain useful information. A discrepancy may occur between authority and the level of technical knowledge. The more diversified weapons become, the more the personnel training profiles differ. Mutual understanding and interaction become more complicated in this connection. This inevitably results in an increase in the uniting role and strength-

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\(^1\) Referred to here is R. Shekli's tale "Bilet na Planetu Tranay" [Ticket for the Planet Tranay].
ening of the authority of the commander—the one-man manager—who, though not as familiar with each form of weapon as his subordinates, is capable of coordinating actions in view of his broad background and complex systems knowledge. But broad knowledge is not enough, comprehensive special knowledge of all fields is also required. Group effort actively combines all who can be of use.

Implementation of Decision. In order to implement the commander’s decision it is necessary that it be understood by all subordinates and that it be embraced by them. The Marxist thesis that an idea, embraced by the masses, becomes a material force also pertains in full measure to military affairs. Only a thorough understanding of one’s assignment, its place in the overall mission, and firm conviction as to the validity of actions can engender initiative and desire to carry out an order at any cost. This requires great discipline, high morale and thorough understanding of the situation and content of the decision. Information channels at the disposal of the commander (including technical systems and personal communication) make it possible to state a problem to any subordinate, but these channels, in view of the limitations of the language and time, are not enough for transmitting the entire scope of a concept, for analyzing concomitant circumstances, or for internal conviction. The situation is altogether different if a certain group participates actively and directly in the decision making process. The group as a whole and each individual are united by direction, the course of thoughts, a single idea, born outside of, but at the same time within each individual. Under these conditions another’s opinion, criticism, even abstract remark may play the role of “triggering mechanism”, producing an “avalanche” of new ideas. Mutual understanding of cooperation emerges, which cannot be achieved through the most detailed explanations. While the decision is being implemented, new information is obtained and the situation changes; the real course of events often deviates from the plans. It is not always possible to exercise complete and continuous centralized control in all stages of military actions. For this reason it is necessary to instill the spirit of the decision in subordinates, so that they can direct their obedience and initiative toward it. Such a problem is better solved if subordinates think together and participate in the decision making process.

At the same time there are also problems in collective work.

Insufficient Transmission Capacity of Communication Channels. With the aid of technical systems and special language it is possible to increase to some extent the transmission capacity of the auditory channel and to connect to it a visual channel. There is, however, a serious limitation: under certain conditions, particularly during intensive mental work, the brain itself becomes an information barrier, strengthening the selection of the flow of communications.
Distortion in the Information Exchange Process. By this we mean both technical and linguistic distortions: poor expression, poor choice of words—all of this is equivalent to noise, which is superimposed on basic information. The result is ambiguous understanding.

Branching of Decision During Decision Making Process. This means professional and individual specialization of a problem. The more concrete a definition, the greater the degree of subdecisions (parts of a decision), acquiring independence, diverging from each other, like branches of a tree spreading from the trunk. It is extremely important that the correspondence between the subdecisions, plan and the goal be controlled. Such control requires thorough and comprehensive knowledge of the concept of the decision, i.e. a clear understanding of it. Each person, of course, is more deeply instilled with the spirit of his own decision. Therefore only a one-man manager is capable of a timely detection of extraneous branches on the tree.

The sense of group responsibility is specific and it cannot be defined the same as the sense of individual responsibility. A group is sometimes prone to limitless trust, particularly in the presence of long friendly ties. The volitional factor is most markedly manifested in man when he is given the rights of a one-man manager.

The discussion presented above does not exhaust all the features of individual and group activity. We mentioned only the ones that are most important with respect to decision making.

2. The “Supervisor-Subordinate” Group

A group with common interests, the members of which have individual, but not completely compatible interests, is called a coalition (a pure mathematical term here). A group of completely compatible interests is defined as a cooperative.

We will examine the activities of two adjacent rungs of the hierarchical ladder. This specific group operates in the attitude of mutual subordination. We will conventionally call it an S-S group (Supervisor-Subordinate group). An S-S group, depending on intrarelations, may act as a coalition or as a cooperative. In a cooperative (in contrast to a coalition) all conflicts are resolved for the benefit of common interests. A coalition is often formed at the beginning of group activity, which may endure, grow into a cooperative, or may collapse. It is worthwhile to establish just how this happens.

Mutual obligations exist in an S-S group.

The responsibilities of the leader are to:
—Assign tasks which can be completed and which promise success;
—Supplement resources (with personnel, equipment, information about the general situation);
—Organize interaction.
The responsibilities of a subordinate are to:
- Complete the assignment;
- Provide information concerning his capabilities (material and mental resources);
- Provide information about the enemy in his sector.

It is assumed that an S-S group operates for a long period of time. The effectiveness criterion for the members and for the group as a whole is the overall success with limited overall resources.

Decisions made by the supervisor and subordinate are based on effectiveness and responsibilities. The subordinate is interested in success and preservation of viability (replenishment of resources). Both too small (little success) and too difficult (high use of resources) tasks are undesirable for him. The acquisition of information about the enemy and about his own troops also requires expenditures (for example, reconnaissance of the battle or increase in the number of headquarters personnel). The lack of information detracts from the success of the subordinate. Therefore economizing on reconnaissance must be very circumspect. The subordinate tries to increase his resources and for this purpose he may underestimate his capabilities and overestimate his difficulties (we will not discuss the permissibility of such behavior for the moral-ethical standpoint at this time). Such an attitude, however, may lead to the assignment of unpromising tasks; another point that must not be forgotten is "punishment": reduction of resources because of a bad reputation.

Let us turn now to the supervisor. Problems that are too difficult will not be solved and will involve great losses. Subordinates must be supplied with resources, and future actions and the unfolding of events must be considered. It is not always possible, in achieving a maximum overall success, to have each subordinate succeed in his task. In exceptional cases, one may have to sacrifice part for the sake of the whole. All of these are conflicts. There are special optima of conduct relative to each subordinate, but there may be no absolute optimum, and if there is one, it is most impossible to find it, since the supervisor and the subordinate have different information, and consequently they evaluate the situation differently. Compromise and reconciliation of conflicts are impossible and the conflicts must be resolved radically.

It is possible to trace to some extent the activities of an S-S group in a coalition game. Groups A and B, consisting of two players each (supervisor and subordinate), competed in a tactical problem. The situation was plotted on a map. Each subunit (depending on the branch of service) was assigned a weight in conventional units. Success was evaluated in the same units. The overall weights of the forces of each side were equal. The total resources (for the entire cycle of problems) were limited, but they increased when a mission was accomplished with 50% success. The players were required to make several decisions
within a limited time, and these decisions were evaluated by referees; rewards and penalties were awarded (in conventional units), depending on the result. The situation on the maps of the players differed from the situation of the referees: the supervisors had less detailed data than the subordinates. In addition, nonidentical distortions were introduced.

The first step was to analyze the maps and have the subordinates give their supervisors information about the situation. It was permitted to introduce distortions so that the resources of the subordinates were increased by 20% of the distorted conventional units (ours or the enemy's—it made no difference). This “prize” could be used as seen fit. The purpose of “rewarding for mistakes” was to consider the possible economy of forces for reconnaissance and data processing. In the second step, the supervisors made information decisions on the basis of their maps and data obtained from subordinates. In the third step, the supervisor made an operational decision: they assigned tasks and allocated resources (with consideration of previous results). In the next step the subordinates made their own detailed operational decisions, after which all the data were fed into the referee system for analysis. If the overall success fell below a certain level in five consecutive missions the coalition was considered destroyed.

The game by no means simulates practical situations, but interesting psychological collisions do occur in it. It evokes competitive interest and unfolds seriously. A typical course of competition is presented in Table 9.

At the beginning, both sides had equal forces—100 conventional units each. The tactical situation was also about the same. The subordinates prepared their reports for the supervisor differently: the subordinate of Side A distorted 20 conventional units (reporting correct data relative to 80), and the subordinate of Side B distorted 30 units. The supervisor of Side A, in his stated assignment, required a gain of 10 units, and the supervisor of Side B asked for a gain of 15 units. The subordinates made decisions, and after the referees evaluated them, it was established that Side B should lose 10 points. Since Side A completed its mission, it received 10 reinforcement units and 4 “reward” units for the distorted information. Their forces increased to 114 units, whereas the forces of B decreased to 96 (with consideration of 6 “reward” units). In the second and third games, Side A won again; more in the third game than the supervisor expected (20 points); but Side A was replenished only to the extent of the accomplished mission. In the fourth game the supervisor of Side A, disturbed by his mistake in the third game, assigned a task that was too difficult. This resulted in an unsuccessful solution and Side A lost 10 points. Side B, however, did not receive reinforcements, since its success was accidental and the statement of the problem was not planned.

Side A played well in the third and fifth games and scored a decisive victory in the sixth game. Starting with the sixth game, a cooperative was formed in the group of Side A. Side B was penalized for subordinate’s
Table 9.

<table>
<thead>
<tr>
<th>No. of game</th>
<th>Initial forces (conventional units)</th>
<th>Information from subordinate to supervisor (conventional units)</th>
<th>Rewards for mistakes (conventional units)</th>
<th>Importance of mission: Success of coalition (conventional units)</th>
<th>Incentive for accomplishing mission and replenishment (conventional units)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>A 150</td>
<td>B 100</td>
<td>A 4</td>
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<td>192*</td>
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</table>

*S-Cooperative.
great inaccuracies in the situation report; the “rewards” and the unjustified difficulty of the assignments handed out by the supervisor (in the hope of a big win) helped little: more was nearly always lost than was planned. Side A also was not absolutely accurate, but it nevertheless made fewer mistakes: it received 27 “reward” points in all games, and Side B received 36. Themost important mistake made by the supervisor of Side B was that he could not correctly evaluate the situation after the first loss and assigned missions that could not be accomplished; this was also the result to some extent of mistrust toward his subordinate, who concealed the situation. The cycle of the games was repeated with another coalition of A, whereupon everything went differently: after the first loss the supervisor of Side B assigned a task of losing not more than 20 points; a defensive decision (not to win) was made in application to this task, which made it possible to lose nothing. The supervisor of Side A, planning to win, was penalized and the forces were equalized. The laws of distribution of the characteristics of the games are illustrated in Figure 33. In the coalition “overall success”, “subordinate’s information” and “incentives” have trimodal distributions (with three maxima); the “importance of the mission” has a unimodal distribution. These laws reflect the style of joint operation of coalitions. The style changes when the supervisor and the subordinate change places. In the cooperative all distributions are unimodal (this may be used as a criterion of difference).

Three characteristic variations of coalition behavior can be distinguished:

1. Optimum fulfillment of coalition responsibilities. The partners often worked harder to please each other than in competing with the enemy.

2. The partners were not concerned about the coalition. This never insured long-term success and the coalition usually collapsed.

3. The partners worked harmoniously when their ideas about the enemy’s intentions coincided; but if they did not coincide, attempts were made to conceal some of the information in order to orient the coalition partner toward the desired direction. The fraction of coalitions that fell apart here was minimum. The conversion from coalition to a cooperative was most often preceded by this kind of behavior. The partners understand each other well; the subordinate releases only part of the information to the supervisor, but the most important part of it (for this he receives “rewards”).¹ The “incentives” and “reinforcements” increase as a result of success.

Cooperatives do not revert back to coalitions, but in certain cases they collapsed under the pressure of failure. Cooperatives almost always won at the expense of the coalitions.

¹ In this case the “rewards” are justified. The supervisor and the subordinate work together so well that they need expend minimum resources on intercourse.
One of the most important management problems is to insure that groups work from the very start as cooperatives, and not as coalitions.

3. Forms and Structures

The effectiveness of the decision depends to a great extent on the form and organization of operation.

The simplest form of joint operation is discussion of the problem solving plan. It is assumed that the plan is prepared, it is understood and discussion is carried on. Each participant first analyzes the plan in the light of his own specialty and proposes additional considerations. During discussion the strong and weak sides are disclosed, the main part of the plan is crystallized and the attitude toward it is determined. The decision is worked out on the basis of the plan. The discussion does not necessarily lead to agreement: contradictory opinions are considered during decision making. It is important that the discussion be conducted actively and each participant present and settle substantive arguments, using his inner conviction as the guideline.

The following, more complex form of collective activity is the development of the plan. It is assumed that the basis for the plan exists, but it is not yet completely formulated. Development, detailing, and definition of the plan are required in accordance with the specializations of the participants, after which a decision is worked out. It is necessary to determine the steps of implementation of a decision, assign the tasks to the troops, determine the means of deployment of weapons and the means of interaction. If unity is not achieved during the development process, variations of the decision or of parts of it may be proposed and arguments may be presented in behalf of each variation. The final choice is left to the commander.
The combining of proposals is employed in cases when a decision must consist of rather weakly connected parts. It is assumed that the idea of the general decision exists, that the autonomy of partial decisions derives from it and that proposals (both agreed upon and disputed) are formulated. The task of the decision preparation group is to combine proposals, eliminate contradictions, reconcile them in terms of time and space, and determine the specific means of implementation.

The following forms of group activity are different from the preceding in that they do not have an initial plan or idea, which may serve as the basis of group activity.

**Joint Development of Decision Variations.** The starting point in this form of group activity is the general decision of the senior commander, i.e. the statement of the problem. The basic factors are selected and evaluated on the basis of information about the situation. Proposals are heard, analyzed and adopted. The versions lead to a specific level of definition. On the basis of evaluation the versions may be discarded, improved upon, expanded, altered or combined. When agreement has been reached on the competing (in terms of effectiveness) versions, the versions are submitted to the commander.

**Joint Thinking.** This is the highest form of group activity for which one should strive. An operational group must conduct the entire cycle of decision preparation with maximum intellectual contact. From the beginning of familiarization with the situation to formulation of the decision, all members of the group should learn and understand the way of thinking of each individual. The concept behind the decision should embody everything that is useful, and express the will of the group.

Group activity is based on the character of interactions (relations) among the individuals, chief of which are the following:

—Command relation (leadership); this relation need not be determined by service rank; it may occur spontaneously, adaptively, during the process of group activity;
—Relation of interaction; agreement of actions is presumed in the interests of the common goal;
—Relation of information; mutual exchange of data about actions and intentions;
—Relation of notification; exchange of information about the situation.

The character of interaction determines the requirements on the transmission capacity of the communication system, by means of which information is exchanged.

A second important factor is the structure of the group. Forms of structure were examined in Chapter 4. An idea of the dynamics of group activity can be gained from experimental research on the behavior of groups having different structures. Such research reveals several principles. As an example we will discuss an experiment on the preparation
of an information and operational decision. Operational groups of six members were organized with different structures (See Chapter 4). None of the members knew neither the structure nor his partners; only the number of direct communication channels was given. Each member received a partial description of the situation and the right to exchange written messages through a referee. One of the following problems was assigned:

1. Collect the missing information about the situation.
2. Evaluate the ratio of forces ("who is stronger in a given situation").
3. Propose a decision: "attack" or "defend".
4. Evaluate numerically the effectiveness of the proposed decision.

A message could consist either of a question ("Where are the tanks located?"), or of a reply ("I have no information about the tanks."); other types of communications were forbidden. In particular, it was forbidden to transmit any information without a request. The work of a group was terminated as soon as one of the members declared that a decision had been made. If no such declarations were received in a certain time the problem was considered unsolved. Several formulas (comparatively simple ones) were provided for evaluating effectiveness. Each member was given not more than one formula. One of the problems consisted in the concentration of all the formulas in the hands of certain individuals, since they could not be used separately. The problems were so formulated that solutions were unambiguous. The results of the experiment are summarized in Table 10. The time required by the star structure for solving the first problem was taken as 100%. As seen in the table, the solution of the fourth problem required the most time. The star structure solved it in the shortest time. The central position quickly disclosed the structure, coordinated the efforts and collected the required information. The response was always correct. The second and third problems were solved most correctly by the hierarchical and multi-connected structures, although they required more time than the star structure (the multiconnected structure worked somewhat more slowly than the hierarchical one, but the results of the former were more accurate). The linear and circular structures did not work as well as the others; exchange of information within these structures was sluggish, with numerous futile requests that had no bearing on the problem. Specifically, these structures compiled the greatest number of unsubstantiated declarations that a decision was made. As experience accumulated, the speed with which the multiconnected structure worked increased comparatively little; at the same time, the consumption of time decreased noticeably in the star and hierarchical structures. The multiconnected structure exhibited a unique style of behavior. At first the questions were unclear and diffuse in character, information circulated unevenly and some of the communication channels were idle. This "feeling out" period
<table>
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<tr>
<th>No. of Group</th>
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<th>Problem No.</th>
<th>Relative solution time</th>
<th>Percent Correctness of solution</th>
<th>Rejections</th>
<th>Disclosure of structure</th>
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ended unexpectedly. Suddenly a turning point was reached: the activity of all positions increased, correspondence acquired a sharp and precise character, and a decision was reached quickly. This energetic process very rarely failed to achieve results. The fourth problem was best resolved by the star structure, the advantage of which was so great that the initial analysis evoked disbelief.

It was established that the star or hierarchical structure best corresponds to concisely stated problems with complete (though intentionally disassociated) information. At the same time these structures had the greatest dispersion of solution time, which depended not so much on the content of the problem as on individual features of the persons stationed at the central (or top) position. After the problem is made more complex and uncertainty is injected in the information, these structures begin to operate less effectively: the number of rejections and erroneous solutions increases. The percentage of duplicated questions addressed to the same place (this index to some extent characterizes confidence in one's actions and in the validity of the solution) increases for the star and hierarchical structures as the complexity of the problem increases. Conversely, the capabilities of the multiconnected structure are manifested to the greatest extent in complex problems with incomplete and even contradictory information. There were practically no rejections and the percentage of correctly solved problems was considerably higher. The work load of the communication channels approaches uniformity as the complexity of the problem increases. Characteristically, the problems for which there is no solution are comparatively quickly discovered by the multiconnected structure. The other structures work futilely for a long time on unsolvable problems.

An interesting experiment was conducted to determine the suitability of the various structures for making organizational decisions. The problem consisted in determination of the optimal structure for managing subunits, the functions of which are interrelated. The functions and the relations among them were described and distributed among the participants in parts. A joint goal was also formulated. Since the problem was described verbally and not mathematically, no exact solution existed for it; therefore evaluation consisted of a comparison. The hierarchical, star and multiconnected structures gave the hierarchical structure as the solution, the circular structure proposed its own structure and the honeycomb structure proposed the multiconnected structure. The linear structure did not solve the problem. The solution given by the hierarchical structure was in all probability the closest to the optimum solution.

The advantage of the multiconnected structure in its solution of complex problems was indisputable. Moreover, this structure is organizationally the most complex one and also the most expensive one in practice, since it requires maximum number of communication channels. The multiconnected structure is the slowest one, and sluggishness and high cost
rapidly increase as the number of participants increases: 20 participants in the multiconnected structure could not solve in four hours the problem that the star structure easily solved in 35 minutes. With a large number of participants the hierarchical structure, as one might expect, performs fastest of all, although it made more mistakes than the star structure. The circular and linear structures work satisfactorily on simple problems that do not involve a great deal of information; they handle such problems better than the other structures. The multiconnected and honeycomb structures exhibit the least reduction in the qualification of its participants, but only if they do not fall into a supervisory position.

The capabilities and inadequacies of specifically oriented operational groups with various structures were determined experimentally. The experiments can assess the ability of the structures to use various decision making methods, forms of group activity and means of intercourse (communication).

We turn now to the question of the methods of group activity in decision making. All methods described in preceding chapters are effective methods, but certain features should be pointed out. The first concerns the use of the general problem solving system. A group of persons organized in a certain structure, analyzes the corresponding system in general form, specializes it in application to the class of decisions (information, organizational, operational), works out specific methods, distribution of functions, and interaction on typical problems. This part is the preparatory work and precedes the training stage. Training is administered by a person who is not included in the structure. The purpose of training is group mastery of techniques, development of skills, gradual improvement of accuracy and speed of joint work. Control of the training process and analysis of each problem are necessary for disclosing weaknesses in the structure and in training individual persons.

The second feature is related to the collective search for ideas. One of the interesting techniques of this type is sometimes called “brainstorming.” This method has found practical application in industrial creativity in the last decade, but its origin dates back into antiquity. No external organizing principle is introduced in the work of the group, but the internal elements of organization develop spontaneously. The operation of the group (no constraint is placed on the composition) is preceded by brief psychological training. It diverts the people from routine concerns and customary lines of thinking, focuses attention, breaks personal connections with people and events, creates a good attitude, weakens self-control and responsibility and, in the final analysis, “liberates the mind from its fetters.” Discussion of an engaging hypothetical history, similar to the situation, is considered useful. This is followed by brief and unobtrusive information about the situation and statement

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1 Erikh Yanch, Prognozirovaniye nauchno-tekhnicheskogo progressa (Forcasting Scientific-Industrial Progress), Moscow, Progress, 1970.
of the problem. Then comes the central step: each presents his proposal, basic concept, briefly and concisely (1 and 2 minutes per presentation). Questions, explanations, clarifications, discussion and criticism are not permitted. No limitations are imposed on the substance of an idea: it may be fantastic, taken from another field, absurd at first glance and as far from reality as one wishes. A profusion of thoughts, considerations, conjectures and theories is all that is required.

All statements are recorded verbatim for subsequent analysis, which is done by a group of experts, organized in a multiconnected structure. The ideas are classified, relations are established and classes are selected if they have a direct bearing on the problem. The assumptions on which each concept is based are ascertained. The characteristics of the assumptions are systematized. Feasibility, possible outcomes and risk are evaluated. Attractive ideas are selected and described, and assumptions are formulated and compared. Finally, alternative decisions are prepared.

Another method of searching for ideas is play games. The importance of games in human development and activity is hard to overestimate. By and large we do not give consideration to how great the game element is in our behavior and in our entire life. After a short period of training most people are, to a considerable extent, capable of role playing, of understanding another’s role and playing the part for time. War games were developed in ancient times and served as one method of operational-tactical training. The first formal description of a war game appeared in 1789; it occupied 60 pages of text. The development of statistical games theory and computers that simulate a real situation by means of mathematical models, elevated war games to a high level.

The chief advantages of games are their sporting, competitive form, which mobilizes internal efforts, and creates interest and other positive emotions. The atmosphere of competition facilitates psychological penetration into a role. The war game involves a conventional ritual which creates the required frame of mind. Preparation for a game includes the formulation of an intention and plan, of initial data and organizational measures, determination of the number of players and the tempo of the game, determination of the structure of the groups, rehearsals etc. Three groups are usually formed for playing a game: players, trainees, and umpire. The playing of a game for preparing a decision requires a game plan, description of a situation and distribution of roles. A description should contain quantitative and qualitative elements. The quantitative description must be expanded to the greatest possible extent in order to afford the possibility of using the computer and for increasing the reliability of evaluations.

However the infinite variety of life, which cannot be made to sit within a digital framework, must be borne in mind. Pseudoscientific mathematical calculations, such as the laying out of certain ideas according to a scale of weight coefficients (night rest—zero, day rest—10, feeding—30,
fighting—100) cannot be taken seriously. The game is played after the plan, rules and roles are studied. The conduct of the participants, their decisions and considerations with respect to questions that have a bearing on the stated problem, are established, systematized and processed. Changes are made in the game plan on the basis of the results and as many matches are played as are required (with or without replacement of players). When playing war games of an exploratory character, the players should strive for maximum freedom of will and independence from the opinions of persons in authority. The actions of the players should not be evaluated if the games does not pursue scientific purposes.

A given problem can be solved by various methods in various groups. This not always possible for the preparation of operational decisions where time is limited, because the adequacy of the method takes on particular importance. The following recommendations can be made on this question. The use of methodical problems solution systems is always helpful if a group is prepared and has the corresponding technical support. Games produce satisfactory results in undefined problems in which sociological and psychological factors have high specific weight. A “brain storming” sometimes brings salvation in a situation that at first glance appears hopeless.

Each group usually exhibits preferred forms of work, which are developed during cooperation on the basis of personal preferences and inclinations. It is better that a group master various forms developed systematically and purposefully.

We spoke above about the stereotyping of individual thought. Group thinking may also be stereotyped if only a narrow method is used repeatedly. When organizing a staff it is essential to observe a sense of proportion: avoid being overloaded with methods of special character, but do not place absolute faith in any method, no matter how effective it is. Most important is the correct choice of personnel. One should proceed primarily from the purpose of the group, determined by the class of decisions that are to be made, such as: continuing activity for the purpose of making organizational decisions, an operational duty group, a command post, a group for one-time action for analyzing an exceptional situation, etc. The group should include persons with various specialties, embracing the entire range of problems. Consideration of individual qualities is most difficult. There are no ready formulas here, since the contingent from which the persons are selected is always limited. The personality of the commander organizing a group has a great influence. The following factors should be taken into consideration: differences in specialization and training, perception and memory, capacity for analysis and computations, emotional state, range of contacts, excitability and stability, psychological and physiological endurance, proneness to fantasy and clearness of thought, calculation, caution, ability to have others obey his will or, conversely, to submit to someone else's
influence, ability to create a friendly situation, tact, sense of humor, straight forwardness, integrity, decisiveness, responsibility, initiative, organizational ability, mutual liking, mutual understanding and mutual assistance.

A well organized and firmly directed group has a remarkable ability of synthesizing positive qualities, of creating an atmosphere of mutual reinforcement and suppressing negative emotions and properties. It is desirable therefore, that a group be made up of persons with various temperaments and opposite tendencies.

The desirable relationship between the qualities of individuals is also related to the structure. The star (excluding the central position) and multiconnected structures are the ones least sensitive to individual features; the former—due to rigid centralization, and the latter—in view of communications. The hierarchical and linear structures are most sensitive to the group. The top position in the hierarchical structure has no direct contact with all elements of the structure. It may be poorly informed about disagreement and may not be able to exert its influence (particularly if this is prevented by intermediate levels). The presence in the linear structure of one element with little contact may destroy the information flow.

The forms and features of collective work exert an influence on the requirements imposed on the organization of a group. Brain storming is least dependent on personal properties of the group, and a methodological system is most sensitive. A game occupies the intermediate position. Joint work in a group educates each of its members and the group as a whole, and therefore correct and steadfast preparation smooths over disagreements. It should be borne in mind, however, that these disagreements may reappear in a complex situation. The commander must penetrate deeply into the essence of the interaction of individuals and groups, placing no reliance on external well being. The functional and mutual correspondence of the elements of the structure may be determined through control problems (tests) and games. The tests should consist of simple problems with a priori known solutions. Training for the tests should be conducted under various conditions, with the exclusion or replacement of various positions in the structure. Games on structures make it possible not only to evaluate the viability of a group, but also to develop working skills. Attention must be paid to variety of tests and games. It is desirable to stimulate sportsmanship with encouragement (both conventional and substantive).

The development of multiposition branched structures in practical activity should be avoided. Large groups are more difficult to activate; they are difficult to service with information systems. It has been proved experimentally that the honeycomb and multiconnected structures with more than 20–25 positions spontaneously break down into simpler substructures, working autonomously. Interaction among these substructures
gradually weakens. If a problem is complex and time is limited, it is better to break it up into several subproblems, each of which is solved by an individual structure. The synthesis of subproblems is done at a coordination level.

It is important to recall here the fundamental conclusion that coordination and final decision making require one-man management.

Let us discuss some experimental data from the analysis of structures. A group with a certain structure was assigned a problem which had several operational solutions that differed little from each other in terms of effectiveness. The versions of the solution were reported to the various persons, so that exchange of information was required for familiarizing the entire group. Three types of problems were analyzed: a) distribution of defensive weapons against attacking weapons; b) choice of objective that should be defended; c) choice of objective to be attacked. The group was required to make one decision.

Each member was entitled to present his decision through an umpire. If during the control time anyone proposed a different decision, both decisions were returned to the authors and work continued. The problem was considered solved if identical decisions were submitted and there were no disagreements. In addition, the following rule was established: the communications channel in the structure, which was not used in three consecutive cycles of information exchange, was excluded. If between two positions without a direct connection were transmitted three consecutive reports through intermediate links, a direct communication channel was established. The star, hierarchical, multiconnected and honeycomb structures were examined as the initial structures.

The decision making time and form of final structure were established; if the resulting structure turned out to be ambiguous, 20% of the connection were omitted. All types of problems produced the same results, in whose reliability there was no doubt. The star and hierarchical structures operated on an average three times faster than the multiconnected and the honeycomb. No substantive changes were incorporated in these structures during the decision making process (in 90% of the cases). The multiconnected structures were transformed spontaneously in 70% of the cases into star structures with a stable central position. The effective process of selecting the final decision essentially began at this moment. Honeycomb structures transformed into hierarchical structures in 50% of the cases and into star structures in 20% of the cases. The top position moved from one person to another in 20% of the problems. In 15% of the cases multiconnected and honeycomb structures did not lead to a unique decision within the control period the star and hierarchical structures had only 7% rejections.

Thus, in problems that require agreement, the one-man management structure spontaneously develops if there are no external obstacles. The one-man management structure does not break down spontaneously; it is
the most stable structure and in comparison with others provides the maximum number of solved problems. Also characteristic is the following fact; if two (or more) active positions develop in a structure, each of which controls some part of the structure, accord is rarely reached: either the structure actually breaks down to two parts (through communication breakdown), or interminable exchange of questions and answers is established between the active positions, while the others become isolated.

An experiment in miniature reproduces what takes place in real life. Many historical examples can be cited to verify the need for one-man management in the making of any, including the most complex and important, decision. *The dialectical unity of collective problem solving for one-man decision making is a principle.*

There is group discussion and analysis, but one-man decision making and management.

The role of the one-man commander in modern conditions is even more important. Only he, on the basis of thorough analysis of a situation, prepared proposals and personal experience, is capable of making the final decision. Only one-man management insures unity and centralization, flexibility and viability.
Chapter 7. Ideal System and Real Capabilities

The great tragedy of science—the slaying of a beautiful hypothesis by an ugly fact.

T. H. Huxley

Abilities, like muscles, grow with training.

V. Obruchev

1. Desire and Achievement

We will try to mentally develop (model) an “ideal decision making system” and an “ideal brain”, and then, comparing them with a real human mind, determine the shortcomings of the latter and whether these shortcomings can be supplemented by technical means. We can say nothing, of course, relative to the internal structure of the “ideal brain”; indeed not even the structure of the human brain is completely known. Models of the brain are built chiefly for the purpose of reflecting individual functional aspects of thinking, and by no means the entire process. We will not base our investigations on such models. Instead we will take the following approach: we will determine what we need, and then we will compare the requirements with data on man. We will compare the external characteristics, as is customarily done in systems analysis.

The following functional steps of decision making can be distinguished: preparation of information, preparation of decision, and decision making (final willful action).

We will attempt to evaluate the desired and possible in each step.

The first step includes the following functions:

1) Presentation of information, i.e. conversion of input data for further utilization;
2) Perception—assimilation (understanding) of the information, conversion into primary thought categories (classification) and memorization;
3) Analysis—investigation of all properties and internal relations their classification, ascertainment of characteristics and laws;
4) Comparison. Any situation (consequently information about it) and any action to some extent, repeat the past and to some extent are
new. By comparison it is possible to determine the new and the old, make a preliminary judgement about the complexity of the situation and the completeness of its representation.

The second step is realization of one of the methodological decision making systems. It includes the following:

1) Associations—utilization of similarity and analogy for constructing elements of a decision;
2) Reflection—the ability to represent the enemy mentally and to formulate assumptions relative to his intentional behavior, to explain one’s behavior on the basis of an assumption about the enemy, wherein the assumption includes the enemy’s concept about us;
3) Use of one of the methodological systems;
4) Evaluation—quantitative representation, transformation and comparison.

We will examine in greater detail the content of each step.

The presentation and preparation of information for work is the conversion of information in such a manner that it is reduced without loss to a more convenient form. It is desirable that all the information, regardless of the source and content, be presented in a similar form. A typical example of the presentation of information is translation from one language to another—from one that is unknown to the addressee to one that is known, for example from a foreign language into the native tongue, from natural conversational language to the service, military language (included here are deciphering, decoding, written description, tables and charts).

The flow of input information, which must be received, is limited by the carrying capacity of the auditory and visual channels. The auditory channel transmits approximately 10–20 bytes of information per second (depending on the individual features, content and conditions of transmission). The visual channel is much more productive: some are of the opinion that the human eye has about $10^8$ photoreceptors, which are projected onto $10^6$ ganglion cells (here the information transmission channel is “narrowed” by a factor of 100 and information is selected according to certain characteristics, such as brightness, contrast, etc.). The refractory period is $10^3$ sec. If the receptors retain their independence, then the information transmission rate in the retina is about $10^{10}$ bytes per second. Man requires this enormous speed to obtain complete visual impressions and for pattern recognition. However, the meaning of both printed and oral text is perceived at approximately the same speed. Special training methods make it possible to increase reading speed several fold. In general there are great individual differences in the speed of perception of text or speech. It may be assumed that the figure of 1–5 bytes of mental information per second is close to the truth for most people, and people with an analytical mentality are characterized by a slower rate of perception. If one takes a typical 20 word sentence (approximately
100 bytes) in the Russian or English language and codes it with a mini­
imum redundancy, i.e. “compresses it” as much as possible, one obtains
about 10 bytes of information. Consequently the perception and com­
prehension of one sentence requires 10 seconds. It is theorized that the
presence of redundancy that is usual for natural language, and to which
man is accustomed, has little influence on the speed. Experience shows
that this is the case, regardless of whether speech or printed text is per­
ceived. The reading of a table requires little time, but habit forces us to
think in sentences or otherwise transform dry tabular information, thereby
increasing its redundancy.

Natural language is intended for communication between people under
a variety of conditions; it is voluminous, descriptive and flexible, but it is
less suited for the dry language of facts. A table of the combat charac­
teristics of a missile complex contains approximately 1,000 bytes of
information, presented in words and numbers. Consequently, in order to
receive this information man must use about 15 minutes, which is too
much time for combat conditions. To receive, however, is not to memo­
rize. The process of memorization is even more complex and multi­
faceted. It is thought that the total amount of information that reaches
the brain through the sensory organs is 10–20,000 bytes/second, and
only 1,1000th or less of it reaches consciousness.

Human memory is known to have three parts: operational memory,
in which is stored information that is used in current activity (the least
voluminous), short-term, and long-term (the most voluminous).

Man’s operational memory contains about 10 bytes. Consequently man
can memorize up to 10 random numbers and even fewer letters. The
transmission of words and sentences increases the amount of useful in­
formation. Operational memory is better used by coding messages with
the aid of general concepts. How this is done will be described later. The
description of a concept may occupy several pages or books, but if the
essence of an idea is known to the interlocutor it is possible to commu­
nicate it by transmitting a title, i.e. one symbol. Symbolic representation is
the most economical means of coding. On the other hand, considering
the low volume of operational memory and high speed of data transmis­
sion in the retina of the eye, it is possible to transmit the essence of an
idea through a visual pattern without having to resort to symbols. We
will explain how this is done. All officers are familiar with the concept
of attack, but in order to communicate the plan of attack, even in the
most general form, it is necessary to use much information and many
symbols. The transmission process involves a double operation: first a
sequence of patterns, put together in the brain of one man, must be
transformed into symbols and then transmitted to the interlocutor, in
whose brain the reversed transformation takes place. When a visual pat­
tern is shown, the nerve network of the eye and visual part of the brain
accomplish the transformation.
Between operational, short-term and long-term memorization is the *consolidation stage*, during which a stable memorizing structure is formed. It lasts from a few to 20–30 minutes. Strong stimulation of the brain during the consolidation period leads to loss of the information and forgetfulness (retrograde amnesia). This is particularly important for military personnel. They perform the most important and responsible part of their job under combat conditions; and intensive external contacts (repetitions, discussions, issuance of current orders) are encountered during the consolidation period, which interfere with concentration.

The information capacity of long-term memory is evaluated differently by various physiologists: from $10^6$ to $10^{20}$ binary units, i.e. $2 \cdot 10^5$–$2 \cdot 10^{19}$ bytes. The minimum amount of information in the memory of one man is $10^5$–$10^7$ bytes (approximately 1,000 multiplication tables).

The process whereby civilization develops is accompanied by an enormous increase in information exchange. However, the capacity of concepts, i.e. the amount of information contained in each individual concept or in each idea, increases simultaneously. Thus the brain adapts to an increase in volume of knowledge and complicated relations. The brain, like some other human organs, presumably has more than a 10-fold functional redundancy. Such redundancy insures viability under particularly difficult conditions, and it is usually called upon during evaluation of maximum capabilities. It should be recalled, however, that the activity of the military man in combat is the most stressed, and by no means short-term condition. Therefore it is desirable to use the minimum possible emergency resource. The organization of information, represented in a form suitable for assimilation, is of decisive importance with respect to memorization. This means primarily correspondence to the system of *a priori* knowledge, i.e. to the system to which man is accustomed during training. The similarity of specialties forms the basis for identical construction of the system of knowledge, and frequent intercourse stabilizes and reinforces it.

Identical *construction of the system of knowledge* is by no means construed as *identical knowledge*. The difference between the level of military knowledge of a soldier and a commander of armies is vastly greater than between the level of knowledge of a commander and military historian. But if a soldier and a historian by chance conducted reconnaissance together the commander would sooner listen to his soldier, whom he understands better and faster than the report of an erudite colleague in military science, who is perhaps inexperienced in the difficulties of a forthcoming battle, and less familiar with details of reconnaissance activities. Each man develops his own system for constructing knowledge, and he presents and assimilates new data in accordance with this system. In this sense it is not easy to adapt to an interlocutor, and not everyone can do this, not to mention the fact that such adaptation
requires considerable mental ability, which is preferably used for its intended purpose.

Accepted designations and the method of presentation of the information are very important. Specialized "military language" and charts are helpful in this area, but these means, notwithstanding their numerous advantages, have low information capacity and very high redundancy.

Thus, it may be said that even at the very first step the human brain cannot be considered the ideal system for at least two reasons.

First the low rate of reception and memorization of information; the small capacity of the operational memory; the excessively long consolidation period. Notwithstanding the tremendous capacity of his long-term memory, man cannot use it to the fullest. In particular, he cannot assimilate a large volume of knowledge from the various fields and use it operationally. From among various specialists it is possible to organize a group possessing great knowledge, perhaps even an omniscient one, but this outstanding capability cannot always be used to the fullest extent in view of the low information capacity of intercourse. In order to organize from among a group of specialists an "ideal" system from the standpoint of perception, it is essential to increase by several orders of magnitude the information capacity and to increase by at least one order of magnitude the capacity of operational memory. This would eliminate the "information congestion" in communications and harmful consequences of slow memorization and loss of time to consolidation.

The second cause is related to analysis. Analysis must be based on a large volume of digital and referenced data, which are a poor material for memorization, and which become unnecessary after utilization. There is no time for memorization, and it is a shame to waste efforts and resources on something that will become "ballast" in a short time. The amount of information required for detailed description of a situation in a divisional sector consists of $5 \cdot 10^5$ to $10^7$ bytes, and in practice (in view of the limitations mentioned above) about $10^4$ bytes are effectively used. A change in the scale of actions accompanies a corresponding change of the required degree of detailing a situation, so that these figures are retained for various formations. The information stored in memory cannot always be used completely and timely. Man cannot always determine exactly what information he needs at a given time.

Because of this the capability of analysis is limited. The concealment of the internal relations among the elements of a situation, events, actions and phenomena requires natural ability, willpower and time. The proponents of the associative theory of memory believe that memory is based on the relation between concepts or facts. Actually, the human brain is well adapted for discovering an internal similarity. For example, when attempting to analyze the enemy's actions we seek the similarity between individual elements of his behavior and concepts of attack and
defense, which are fixed in his consciousness. Training and experience increase skill in determining the numerous and obscure relations and criteria of similarity in a short time. However, demands exceed everything that may be achieved in this area even by gifted people. Too much must be discovered and analyzed, and there is too little time for this. The "curse of multidimensionality" is usually overcome by expanding upon the criteria and employing several stages of analysis with different degrees of detailing. This is a well founded and effective method on which is based the systems analysis approach. Its practical application, however, encounters the same difficulty: lack of time, i.e. essentially the lack of information capacity. A very large volume of information must be processed in a limited time. This information may be stored in the memory of the operator, but it cannot be retrieved within the required time, despite the apparent accessibility. The circumstance described below pertains to the essence of processing. Analysis is a form of knowledge. Not everyone can master this knowledge to the same extent. Analysis is very often professional in nature. For example, analysis of engineering installations from the standpoint of radiation safety may require the use of methods in which the commander is not competent. It is impossible to foresee precisely what methods are needed and when, and broad versatility in training may only be harmful.

Most analytical procedures are logic operations, which may be more or less precisely formulated. This is also true (although probably to a lesser extent) of analysis of human relations. The basic difficulty here—incomplete definition and lack of data—does not alter the purpose of individual procedures, but only complicates them by increasing them in number. Many aspects of analysis may be reduced to relatively simple rules, and progress in this direction is a matter of time and effort. Attention should also be directed to the great repetitiveness of analytical procedures. The specificity of analytical procedures and their diversification are also increasing. One should not only remember all of this, but also learn how to apply it. Experience shows how difficult it is to acquire a practical skill in any field; situation analysis and decision making are no exceptions in this sense. Required here, furthermore, are especially distinct and well developed skills for acting quickly, but at the same time not stereotypically. Skill increases information productivity.

Thus, for successful analysis one must overcome the difficulties of combining an enormous volume of memory for data storage with fast retrieval of the data; the knowledge of numerous and essentially different methods and the ability to use them effectively in a very limited time are essential. These difficulties reduce in the final analysis to two problems: expansion of memory (with a sufficiently speedy access to it) and increase in information output. Man must solve these problems in order to approach the "ideal system."

We will now discuss comparison. If a comparative criterion is known,
comparison of data becomes a logic operation. However, the finding of a criterion is in many cases a difficult task since the categories to be compared may be different in terms of content. How does one compare fighting spirit and technical equipment; such a comparison seems meaningless at first glance, but this is not the case. The principle of comparing different categories (or more accurately of factors in different functional spaces) consists in their ordering through transformation, and representation of these categories in a single, general category. The choice of a general category is determined by the substance of the problem. For example, fighting spirit and technical equipment may be compared by determining the dependence of the duration of defense of a canyon on these factors. It may turn out that combat steadfastness and courage play a greater role in mountain passes than the number of mortar implacements. In order to make such a comparison, however, it is necessary to determine what effect fighting spirit and the amount of weapons have on the time of defense by introducing ordering, i.e. by determining what has the greater effect on the duration of defense (even without indicating how much).

Substantiation of the general category, of ordering and measure within it, and also of the method of representation does not enter into the comparison function, and we will discuss this later. However, as soon as it is determined, it becomes necessary to make a set of mathematical (logic) comparisons, to record and memorize the results, compare them and memorize the secondary results, which requires informational output, takes time and makes operational memory more unwieldy. Furthermore, such work is distracting; it is monotonous and requires willpower in order to concentrate.

2. The Range of Intellect

The second step is characterized by the enormous specific weight of functions that are considered purely intellectual.

This step begins with associations. The relations of ideas which lead to a desirable (in terms of the problem to be solved) outcome are defined as associations. By means of associations it is possible to retrieve quickly the required information from memory. Associations are conscious or subconscious. Associations are defined in terms of similarity, contiguity, contrast, simultaneity, etc. Associations usually form a chain, and the first and last links have nothing in common. For example, a jump of thought from the song of the lark to reinforcing the second echelon of the military chain of command is considered absurd, but in reality it is not excluded that the very song of a lark on a June morning may lead a commander through the following chain of thought: lark—azure sky—fair weather—good visibility—visibility far forward and to the sides—front and flanks—foresight—the enemy command has fore-
sight—has he not thought of a flank attack, etc. These are associations by contiguity.

Associations shorten the time of search for ideas, and direct thought in accordance with the connection of ideas. In subconscious associations the entire chain remains in the subconscious, and only its first and last links rise to the conscious level (and here attention often is not focused on the first link). The associative paths from one concept to another may be long or short, fruitful (in the sense of the final idea) or absolutely useless. By conscious effort it is possible to direct association, organize it and shorten the length of the chain. This is what happens in recall. The following method of memorization is also well known. Man studies 100 words. This is his memory vocabulary. One-hundred new words are read to him, which he must memorize. During the reading process each new word is mentally placed in relation to the next learned word and thus an association is established. If a word must be called by the number 67, then the 67th word is first recalled from the memory vocabulary, and then the new word is called by association. The freak with a “phenomenal memory” has long adorned the circus arenas. Something of the sort is consciously or unconsciously developed in each man in day-to-day life and activity.

Associations do not readily lend themselves to organization. Within a class of concepts thought usually wanders from one object to another until it ventures upon something necessary and useful but this lucky moment cannot always be established. The space of associations is not ordered. Therefore purposefulness of search is difficult to achieve. Subconscious associations are the most disorganized. The randomness of associations increases the chain building time. Will, skill, and the familiarity of the range of ideas contribute ordering to the process, shorten the length of the chain and thereby shorten the time. This narrows the range of associations and consequently reduces their usefulness to a considerable extent.

Two types of associations are helpful in applied activity: purposeful—closed in a limited circle of ideas, and broad—free, limited essentially only by the content of memory and emotional qualities of the individual. Both types exist in a unique competition. The former operates with categories close to the object of thought, re-sorting them in different variations; here any association is useful to some extent, but it is hard to hope for an original idea. The second type is most often unsuccessful, but in rare cases it may lead to an unexpected result in terms of its importance, fundamental nature and future prospects.

Associations occupy the operational memory, require attention, time and willpower. Their competition may lead to conflict (not only within the individual, but also within the group): on the one hand something must be compared with something else; on the other hand it is desirable and interesting (perhaps very important) to strike out in a different
direction. Conflict leads to elimination of some perhaps very useful association. The expenditure of informational output on associations can never be considered adequate: there are no limits here. The difficulty of combining organized associations with free ones in one mental process is aggravated by the great amount of information that must be processed. It is obviously better to separate organized, more accurately formalized associations from free ones.

Thus, in addition to what was said previously, we should point out the inadequate and by no means ideal capacity of man to separate and rationally utilize associations.

We have encountered reflection in all decision making methods. Reflection is the act of recognizing the process of imitating the enemy's reasoning or imitating the possible behavior of someone with whom business is to be conducted. For example, the formulation of a plan of attack requires the tracing of the course of reasoning of the enemy in relation to our actions. Reflection is the representation of what is taking place in the "heads"—both individual and in groups. One form of reflection is the war game. During the game, each side evaluates the motives and behavior of the other side, and this is reflection.

The boundary between analysis and reflection must be determined and learned. During analysis we take the position of a bystander, an objectively judging third person, who knows the situation, has all the information known to each player and seeks the most important relations that determine the situation and behavior, or the optimum methods (strategies) that insure the best result for each of the players. Armed warfare or a war game requires of each side the development of the model of the enemy, reproduction not only of his objective situation, make up of forces and weapons, but also of his internal world. If two players (2 groups) take part in a war game, then each of them stands on one side of the front line. If the game takes place in the mind of one man, he must in turn change positions and simultaneously his idea about the other side. This is not a very fruitful endeavor: everyone knows how little reward is derived from playing a game of chess alone. Therefore war games are conducted with designated sides. Each side uses reflection for constructing a model of the other side. The "depth of penetration" into the ideas of the enemy about oneself is characterized by the rank of reflection."

We will examine this in more detail by a model.\(^1\) A and B are opponents; let A pursue B. B hides in a cave from which there are two escapes: an easy one and a hard one. For various ranks of reflection the considerations of the players will be the following:

1. The rank of reflection of both opponents is 0. One does not

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\(^1\)V. A. Lefevr, *Konfliktuyushchiye struktury* (Conflicting Structures), Moscow, Vysshaya shkola, 1967.
imitate the judgements of the other. In this case B takes the easy way and A also takes the easy way. The result of pursuit is determined by the ratio of speeds.

2. The rank of reflection of A is 0 and rank of reflection of B is 1. B will deliberate as follows: “A undoubtedly will take the easy way. Therefore it is advantageous for me to take the hard way.” B eludes pursuit.

3. The rank of reflection of A is 2 and the rank of reflection of B is 1. B will deliberate as before and will take the hard way, but A will deliberate as follows: “B thinks that I’m going to take the easy way, and for this reason he will take the hard way. But I, of course, will take the hard way: indeed B cannot anticipate such a move.”

The formation of even higher ranks of reflection is obvious.

Reflection, however, is nothing more than a military (or in general, a conflict) game. Reflection is the reproduction of the process of interaction of two (or more) subjects with consideration of the knowledge and ideas of each subject or of all others (including oneself) in all completeness and depth. The objects may be opponents, the environment, an organization and their individual elements. If reflection could be complete and thorough, then a decision would be indisputable. However, lack of information about each of the subjects and many other factors necessitate a check of reflective conclusions. Nevertheless reflection is a great gift, by virtue of which man constructs his own imperfect, but personal and original internal world of relations: he may ponder reality, gazing keenly into such nooks and crannies of life and another’s thinking which would be impossible to penetrate by any other means. For this man pays the price of internal conflicts, a struggle between knowledge and notion. Therefore, reflective ideas should be rigidly controlled to prevent futile and unfounded thoughts from dominating over accurate evaluation and common sense. The remarkable perfection of thought is concealed in the dialectic unity of reflection and control.

And so, reflection is the property of intellect, and at this time we know of nothing else like it. Attempts at mathematical analysis of reflection cannot be considered futile, although they have not yet produced perceptible results. Modeling of reflective functions is in itself an interesting endeavor and may find application, but this is nothing more than the reproduction of mental processes that have already been thought out and repeated more than once. It is difficult to imagine that great achievements will be made in this respect in the very near future.

By analyzing the psychophysiological essence of reflection and its “material support” it is easy to discover serious deficiencies, which in one way or another prevent more effective utilization of reflection in decision making. The rank of reflection depends on inherent abilities, social upbringing and breadth of knowledge. Without corresponding training it is difficult to rise above the first rank of reflection. Reflection
is purposeful, so that the rank of reflection that is within the grasp of any given individual differs in the various fields of endeavor.

A commander must have a high rank of reflection in many areas, especially tactical, operational, political, social and psychological. Education and the development of abilities for reflection are matters of training. Each person in a group may construct a reflective model applicable to the field in which his capabilities are strongest and his knowledge more complete. Efforts are combined to construct on the basis of these models a general model of sufficiently high rank. However, the limited information exchange between various persons in a group stands in the way of collective reflection. Communication is even more difficult if the group is not concentrated in one place and the persons comprising the group are separated by great distances.

Thus, in view of the insufficient informational output of natural means of communication among people, both a group of persons and the individual alone are far from ideal.

The subjective state of a person has an influence on reflection. The absolute rank of reflection of a specific person does not always remain the same. Can it be increased or is it possible to prevent its reduction? This question has long bothered physicians, psychologists and engineers. There are reasons to assume that reflection can be stimulated by external action, recollection, a nudge, demonstration of some similar episode, or conversely: by diversion and relaxation. Stimulators are required for exerting such an influence. The method by which stimulators are used may vary: external stimulation or self-stimulation, when a persons “calls” for information which, in his opinion, may help him. This requires controlled means of storage, selection and display of information. These systems must have a large memory (including operational) and high productivity: sufficiently frequent replacement of patterns (visual or audible), along with the content of patterns, plays an important role.

There is one more aspect which should be discussed, namely objective evaluation of the state of the operator. A commander cannot always choose the time to think out a situation and make decisions (although he has certain capabilities in this regard), but he may be convinced that the people enlisted in the work are “in form.” Self-evaluation and subjective evaluation in general in this case are no more than reflection of a certain rank, and this is what we want to determine. Objective evaluation of the rank of reflection might be very useful. Apparently the use of special tests might not only solve the problem of control, but also alter in certain cases the state of man, create a certain attitude, concentration or anything else that we do not yet know about. The storing of tests and analysis of answers require memory, presentation of information and communication.

The evaluation function described below basically requires the carrying out of calculations. If intuitive evaluations of a comparative nature
based on elementary calculations were permissible in past wars, then such is no longer the case.

The armed forces have been altered beyond recognition in recent decades, and mathematical description of combat actions has traveled the road from Lanchester's equations, which occupy two lines, to effectiveness functions, the writing of which requires dozens of pages of compact mathematical text. The most qualified group of mathematicians cannot compute such a function in the mind, on paper or on a sliderule, even if such a group were larger than a wartime field army. The reason for this is not only the volume of computation, but also their diversity.

Numerical evaluations are ubiquitous in all fields of military activity: supply and logistics, operational data processing and management, organization and staff structure, military psychology and sociology. Each one of them has its own specific features.

Evolution did not endow man with special ability for doing mental calculations. The ability to read and memorize many numbers is comparatively rarely combined with high intellect. At the same time the ideal problem solving system should be able to do many calculations quickly.

A mathematical tool has been developed for estimations, the use of which is possible only with the aid of computers; man is not able to do it by himself. Consequently, man is not only not ideal in this regard, but even helpless in most cases.

3. Synthesis

The concluding and all-embracing stage of the thinking process is synthesis (Figure 34). Synthesis is the apex of creativity. In synthesis the results obtained in previous stages are employed and a model of the solution is constructed, which is optimized and refined to final form. Synthesis requires great effort and concentration, since errors that are committed cannot be corrected. Since synthesis may include reexamination of the initial positions and mutual checking of the results, the amount of information that must be processed is very great. In essence, synthesis includes two basic procedures: selection of basic elements of which the decision consists and formulation of the solution. During fulfillment of the preceding functions it is necessary to develop ideas, assumptions, plans and variations from which the most useful and fruitful version is picked. Therein lies the problem of selection. Selection and formulation of the solution are closely related, mutually excluding and mutually penetrating procedures, which comprise a dialectical unity. Dialectics consist here in the fact that the selection of elements of the solution (since the selection is final) contradicts the freedom of formulation, and formulation, as the concluding procedure, limits selection. At the same time, selection without formulation is meaningless and formulation without selection is impossible. The function of synthesis is most complex, therefore there is never any certainty that thought re-
Can the ability to synthesize be reinforced by any technical means? This question is now the object of lively discussions among scientists and it cannot be said that these discussions have been fruitless. Cyberneticists are trying to develop a “thought amplifier”, capable of independently solving problems and even stating new problems, such as the proposal of mathematical theorems. U. R. Ashby discusses the problem of constructing a computer capable of working out the structure of a social organization which “would be stable under the following conditions: unemployment < 100,000 persons; violent crimes < 10/week; and minimum income/family > 500 pounds sterling annually.”

The limitation of such an approach to social problems is obvious, and the 500 pounds ideal can only evoke a smile. But that is not the crux of the matter.

Whether such a machine can actually be built is argumentative. In any case we don’t see how it can be done at this time. Furthermore, if such a machine ever is built, then its operation would require such detailed information about features of human personality, social and economic laws, the existing state of affairs, etc., that it would be impossible to obtain all of it.

Our problem is much better defined and, more importantly, the information is available for its solution. Can technology assist man, and in what way? Turning to synthesis, the “ideal system” has at its disposal a set of possible elements, pieces of the solution, which is in an amorphous or nearly amorphous form. To find the best solution one may examine all possible combinations of these elements; each combination is one formulation of the solution. Suppose there are 10 ideas,

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each of which includes 10 possibilities. Then the number of formula-
tions to be examined is $10^{10}$. If one solution is evaluated every second, 
then the time required is 3,000 years. Even a 10,000-fold increase in 
processing speed yields practically nothing. No other method guarantees 
the best result and therefore cannot be considered ideal. The goal of 
amplifying thought capabilities is to reduce time required for determin-
ing competitive solution formulations, and consequently in increasing 
the effectiveness of selection.

Non-contradiction may be such a criterion: whatever is embodied in 
the solution should not be mutually negated. Negation can be disclosed 
only within the framework of a certain solution model; actions that are 
not contradictory in one model may be contradictory in another. *The disclosure of contradictions* may be the first task of the selection process. 
Selection by non-contradition for a given model is an even more complex 
problem. Man may propose a model of a solution and the computer 
reports to him what is contradictory in it.

Limitations are another criterion. Limitations may derive from the 
relation among the elements of the solution, from the conditions of 
feasibility, from past experience, from instructions of a senior com-
mander, from politico-moral and other considerations. Limitations rele-
vant to each individual element of the solution are used for satisfying 
preceding functions; the discussion pertains to elements within a solution 
model, limited to joint utilization.

A third criterion is agreement of subsolutions. A solution usually 
includes several major parts (subsolutions), and each element of the 
solution may enter into several subsolutions. Equilibrium should exist 
among the subsolutions, since each part depends to some extent on the 
others. If the equilibrium is upset, the solution becomes unstable. The 
discrepancy may be spatial, temporal, in the degree of influence, in the 
result of interaction, etc. The compatibility of solution elements may be 
verified on the basis of formal criteria and may be used as a criterion for 
selection.

What are the deficiencies of the human mind in the creation of the 
model solution? In principle, typical solutions may be used for selection 
if the existing situation has typical properties that permit it to be identi-
fied (if only in general terms) with some situation that may have been 
observed in reality or may have been conceived and studied. Completely 
new situations are not too frequently encountered.

If situations are developed by qualified people over a long period of 
time, and if these people have information about the trends of develop-
ment in military science and technology, then the "library of typical 
situations" may be sufficiently voluminous. Any training process is essen-
tially based on the principle of typification; our rules and regulations are 
condensed from the most typical (and consequently the most general-
ized and important) experience. It is impossible to memorize, however,
several million variations and use them in routine work; technical assistance is required here.

Thus, the function of synthesis is not sufficiently satisfied; reinforcement of mental activity requires high-speed, purposeful selection, recognition and identification of situations, and therefore, expansion of long-term and operational memory and informational output.

We have attempted to shed light on functional deficiencies of the individual and collective human brain in comparison with the ideal problem solving system. But there is more. There are two structural deficiencies that must be mentioned: errors occurring during work and insufficient reliability of the human organism.

Training and natural skills cannot completely preclude errors, miscalculations, oversight and "rejections." Rejection is defined here not as a serious disease or combat losses, but a temporary absence from work, which is poorly controlled externally, but which still disrupts the rhythm of the process and leads to a lower quality solution. Substandard thinking due to physical indisposition is by no means always detected in oneself, and if it is detected, the consequences of indisposition cannot always be evaluated objectively.

Control of the correctness and continuity of judgements yields to formalization but requires great informational output, therefore the direct control of one man over the work of another is not very effective. However, objective psycho-physiological control is widely used in medicine, sports and in work involving responsibility for the lives of many people; it may also be applied to persons performing other responsible functions.

4. Will

We will define the meaning embodied in the terms "will" (voluntas, Lat.), "volitional factor", "volitional action."

Engels considered freedom of will to mean the same thing as the ability to make a decision.

Marxism-Leninism teaches that the basis of will is influence of the objective world, reflection of the laws of reality. Will is the consequence of material processes that take place in the body, a function of the brain and nervous system. But what kind of function is it? To solve certain, precisely formulated problems, a conclusion, constructed by a certain method, is used. Will is essential for the solution of under-defined problems, i.e. problems in which there are insufficient data for arriving at a conclusion. Defined problems are usually solved identically (if a solution method is known). An under-defined problem requires additional definition, addition of the deficient information. Each person does this differently. One of the most frequently encountered under-defined factors is the criterion of evaluation or comparison.
Various models of a problem arise as a result of the various methods of further definition, but a consequence of under-definition of criteria is the collision of several discordant, sometimes contradictory desires, or a conflict of motives.

**Will is the ability to create** (with incomplete data) **a simple and stable** (in terms of a goal) **model of reality and ability to make a simple selection and carry out a method of conduct in accordance with this model.** A change of behavior on the basis of new data or reevaluation of old data is anticipated by the initial model (but not under the influence of an “outside” 1 will).

Experience is a source of information for further definition of a problem (or for finding a means of further definition). Experience may be both individual and collective, and therefore the will also may be both individual and collective. Experience, knowledge and education form will; will is the result of practical activity of some psycho-physiological structure and is not something that is inherited. Let us again recall Engels’ words: “Freedom of will, consequently, is the same as ability to make a decision with a knowledge of the matter.” 2

The manifestations of will are diverse; one of them consists in comparison and selection: what is better, bigger, more important. Quantitative comparison requires measurements in typical units: first it is necessary to know how much, and then to determine what is larger. Man was making comparisons on the basis of social and personal experience long before he learned how to calculate. In order to compare mathematically an apple with a fountain pen it is necessary to introduce a scale of values or utility. Man apprehends the advantages of possessing one object or the other and makes a choice without resorting to numbers. The remarkable property of this mechanism is the fact that it is suitable for comparing entire groups of characteristics and entire sets of objects. The criteria here are qualitative, based on experience. But everyone’s experience is different and requires organization. Will is the organizing factor in the long run. If will is weak it has too little organizing influence, and vacillation, instability and indecision result. One of the manifestations of the volitional factor is threshold transition: the accumulation of criteria (including qualitatively different ones) may abruptly change the result of comparison from “better” to “worse.” The moment of equilibrium is not always ascertained.

We still do not know what is the logic of further definition of problems and how our brain selects the criteria in a conflict of motives. Biological factors, developed through evolution, apparently play a certain role here. However we are not inclined to agree with the biologist Szent-Györgyi who wrote: “The brain is not an organ of thought but an organ of sur-

1 “Outside” argumentation may be regarded as additional information.
vival, like fangs or claws. It is arranged in such a way as to force us to perceive as the truth that which is only a subjective preference. And he who takes a thought to its logical conclusion with absolutely no concern about consequences, must have an exceptional, almost pathological constitution.”

The fact that the brain is an organ of survival cannot be disputed. But it is precisely because the brain is an organ of thought. The brain is not perfect, and under certain conditions it must be reinforced by technical means and by integration of minds.

The volitional qualities are determined chiefly by social upbringing, training and practical activity. Natural data (the mind, character, strength of emotions, vital activity) influence the will in the same way as inherent physical constitution influences physical strength.

The will is a concentrate of realized and unrealized experience, transformed into action.

Technical systems can contain a large volume of data which supplement experience. Moreover, if the corresponding methods are available, a computer can help to further define a problem and objectively refine the value of the criteria, which makes it possible for individual and collective will to be manifested more clearly.
Chapter 8. Language

Empty talk is always easy to put into words.

Goethe

Language is the soul of the nation.

Gogol

Language is the chief and specific tool of a decision making system that includes the commander, operations group, computers and other automation systems. By formal definition, language is a system of symbols that express ideas. Language is developed on the basis of socio-economic attitudes.

A specific living language as a social phenomenon belongs to a large group of people. It exists "in the minds of a whole collective of individuals, because language does not exist entirely in any one of them, it exists in its entirety only in the mass." At the same time, each individual forms his own ideas about the world around him through language. I. P. Pavlov said that man becomes the master of reality through a second signal system (word, speech, scientific thought).

The modern commander must know several types of languages. The first is natural language (native and foreign). Natural language is suitable for transmitting the depth and fine nuances of thoughts and feelings. The proper use of language is a skill and the comprehension of it requires work and talent. A poet can convey an attitude in a few words; this ability is what makes him a poet. Poets have a great awareness of the power of language and of the difficulty of using it. Nikola Nekrasov wrote to Leo Tolstoy: "... I pity my thought, I expressed it so poorly in words." The commander, on whose word depend the actions and fate of many people, must know how to "capture thought with words." The outstanding military leaders have attached tremendous importance to the exactness of language. "... Soviet military theory never has called for the carrying out of two main strikes by one front, but if both strikes were equivalent in terms of strength and significance, they

1 Ferdinand de Saussure, *Kurs obshchey lingvistiki* (Course in General Linguistics), Moscow, Sotsekgiz, 1933.
were usually called ‘powerful strikes’ or ‘group strikes.’ I have stressed this in order to avoid confusion in operational-strategic terminology,”¹ wrote Marshal of the Soviet Union G. K. Zhukov.

The military man must know the language of military symbols, with the aid of which the situation, battle plan, decision and course of events are displayed on maps. This is conventional language—laconic, precise and simple. No descriptions in the natural language can replace it.

The modern practice of planning combat actions cannot do without mathematical language. Behind any mathematical symbol is either some number (although in calculations it may be temporarily replaced by a letter for convenience) or a numerical operation. Mathematical language gives a quantitative expression of the course and results of thinking. The position of mathematical language should be represented accurately: it aids in reasoning, but mathematical language cannot be used for thinking. Einstein often said that “no mathematician thinks in equations.” Ludwig Boltzman wrote the following about scientific theory: “... Equations are not its essence. A true theoretician economizes in them as much as he can: if it can be transmitted by words, then he expresses it through words.”

A knowledge of algorithmic languages has been essential in recent decades for communication with the computer. This is a specialized symbolic language which permits description of human concepts and reasoning through terms with which technical systems operate.

In contrast to natural languages, other languages are formal. They develop some aspect of natural language, specialize it in application to specific needs, and thereby make language more economical, convenient and efficient. Language of military symbols makes it possible to introduce into the realm of thought additional visual representations and with their aid to use not only hearing, but also sight as means of communication. Only natural and formal languages in combination can completely satisfy the requirements of life. If a single combined comprehensive language, capable of performing a function of both natural and formal languages, ever appears it will not be too soon.

Let us examine certain features of natural and formal languages that are important from the standpoint of automation. Active thinking is constantly being influenced by external information (auditory and visual patterns) and emotions. A pattern and a word merge into one, form a dynamic monolith which embraces the range of emotions. The primary source of a word and of the entire process by which the word is formed could be patterns, which have vanished or have been replaced in our representation. We use the word “zashchita” [“defense”] in a certain sense, although the word “shchit” [“shield”] has not been associated with warfare for a long time, but with electrical engineering (switch-}

¹ G. K. Zhukov, Vospominaniya i razmyshleniya (Memoirs and Reflections), Moscow, Izdatel’stvo APN, 1969, p. 570.
board) or hydraulic engineering (sluice-gate). Many centuries have passed since the time of the initial formation of linguistic forms, and now only specialists in historical linguistics understand such fine distinctions. Words are now connected with new generalized patterns and concepts.

Language has an hierarchical structure, in which more general concepts are differentiated into less general ones, which in turn are again differentiated, and so on to a specific subject level. Thinking may be done on any level of the hierarchy; it is important for mutual understanding that the interlocutors communicate on the same level. Natural language is emotional on any level, and this emotionality plays a tremendous role in influencing oral and written communications. Emotionality is one of the necessary conditions of suitability of language for creative thinking. Natural language has high information capacity. Its information capacity is not limited to formal criteria (the number of letters and words), but also includes word order, usage, etc. In the Haitian language, which has only five vowels and six consonants, information is contained in the structure of the words and sentences, and it is very difficult to learn.

A large amount of information is required for conveying emotion. Four bytes are needed for conveying the word "fear", but after receiving them we do not feel fear. An eloquent description of the feelings of a hero experiencing fear evokes fear to some extent. Can emotional elements be excluded from military usage and can description be limited to a rational representation of events? In no case. In decision making the emotional factor must be considered as one of the stimuli of behavior, and consequently the language of the system which makes the decision must also work with emotions, even though we do not yet know how to calculate the amount of information required for conveying emotions. It would be wrong to assume that the information capacity (including emotional) of language is increased by using complex phrases. Flowery language has the least information capacity and is therefore incomprehensible. Satirizing the scholars, Byron wrote: "Scientists, you explain science to us, but who explains your explanations to us?" The native language is simple, descriptive, emotional and informative. The information capacity of natural language is bought at the cost of complexity and insufficient precision (ambiguity). Information may be perceived differently by different people. Even a dry military order is hard to formulate in such a way that everyone interprets it the same. Natural language has great redundancy, which helps to express new ideas and is a reserve for the development of the language.

When discussion takes place about specific situations, specific estimates and specific actions, the information capacity of language takes a back seat, and precision comes to the forefront. The conditions of military activity do not permit all the information capacities of natural language to be used and do not require this. Ambiguity, however, is in-
admissible. Therefore, a specialized "military language"\(^1\), enriched with additional terminology (this increases its accuracy) and free of little-used constructions, expressions and words, has developed hand-in-hand with military science. As a result, this natural language, used basically in military and professional activity, is more precise but less eloquent.

Let us turn now to some of the features of formal languages. They are artificially developed and therefore are axiomatic and limited in nature. External structural forms appear in them the same as in natural languages (according to certain grammatical rules, individual symbols are combined into words, words into sentences, etc.). Not every thought may be expressed in formal language, but then those thoughts which find expression may be written concisely as possible and are understood in one way. But any change in text, even a very slight one, distorts the content or leads to incomprehensibility. In contrast to natural language, formal language is not redundant: the absolute minimum number of symbols and words is used in each sentence, therefore it is less flexible.

Formal languages are completely devoid of emotionality. The sphere of usage is strictly limited, and therefore, in contrast to natural language, the description of new situations, previously unthought of, requires the development of the formal language. But then, in view of the axiomatic nature of construction, formal languages may be developed in the required direction, irrespective of when their new capabilities are used in practice. The grammar of formal language may also be refined and altered, even the fundamental, primary axioms. New formal languages may be developed as they are needed.

Natural languages do not lend themselves to development for their improvement and do not yield to forcible transformation; they live the life of the people. Dialectics of natural language consist in the fact that it is simultaneously flexible and conservative. Formal languages are more adapted for visual perception, and natural language is best perceived by ear. A written text imposes its own difficulties on perception; in the first place not everyone writes the same as he talks, and in the second place not all the features of oral speech (especially intonation) can be conveyed in writing. An important feature of formal languages is the fact that any one of them may be written exhaustively in mathematical form. Until now formal languages have been developed for application to specific, but more or less clearly formulated problems, and the main trend was comprehensive simplification of language.

The adoption of a new language is a complex and difficult matter. In the development of a formal language, therefore, it is essential to simplify axiomatics, but in such a way as not to limit its service functions. The principles of mathematical language are elementary, since the most complex transformations have simple addition as their starting point. But this did not impede (and perhaps even aided) the mushrooming

\(^1\) i.e. specialized, natural language.
development of mathematics. In a drawn out and futile dispute as to whether mathematical treatments should be written in English or in Latin, Gibbs had the last word, declaring that mathematics is a language. This is indisputably true, but even now not a single mathematical work can be accomplished without a certain number of natural phrases. This is completely acceptable and even convenient to the human reader, but what about the computer? It does not read these phrases, and consequently it does not understand the entire text. It was proposed that special conventional symbols be used in mathematical works instead of words and sentences. However this idea has not yet taken hold.

One of the basic problems of communication is the difference between languages. People can master several languages. Computers use algorithmic languages. The problem of communication between man and computer is one of the central issues in modern science and is one on which many researchers are working. In the military the problem is even more complex: it is essential to insure operational communication between many people and computers. How can a bridge be built between a natural and a formal language? We might try to teach the computer to understand natural speech or develop a new formal language suitable for thinking, for communication among people and for the computer. The former approach is essentially translation: computer operations are possible in formal language only and natural language must be translated into this language. If translation is done automatically, then this will mean that the computer understands natural language.

The tremendous interest which the idea of automatic translation attracted at one time led to the organization of research in this field on a rather broad front. As the investigators penetrated more deeply into the problems, however, the initial optimism gave way to some disillusionment. It became clear that automatic translation is hardly the same as mechanical substitution of words and grammatical construction; a thought comes out differently in another language, and therefore it is necessary to understand it in order to express it. In ideographic languages symbols express words and concepts, and therefore the same hieroglyphs easily penetrate into different languages. Chinese ideographic script includes 48,000 different hieroglyphs and up to 3,000 hieroglyphs are required for understanding even the simplest texts. But then the Chinese and Japanese can communicate with each other through hieroglyphs that are very similar; the difference in language does not prevent this. But if the initial concepts are not the same in a different language, then exact translation is not guaranteed. This difficulty is aggravated in the European languages by the different types of speech forms and complexity of grammatical constructions. Speaking in different languages, people use several different concepts, even when the general trains of thought coincide. The good translator easily discerns the linguistic nuances and conveys the content without resorting to a verbatim translation. It may be assumed
that the scheme of translation takes the form illustrated in Figure 35a; automatic translation is represented by the diagram in Figure 35b. There is a fundamental difference between these schemes, which has not yet been resolved. A person who knows a language first grasps the general sense, on which basis he constructs a translation. But the computer cannot capture the sense. It first makes a verbatim translation and then gradually refines it. With a feel for the language it is possible to penetrate into its sense without knowing the meaning of words. L. V. Shcherba's sentence "Glokaya kuzdra shteko bbulanula bokra i kurdyachit bokrenka," is full of meaning for the person who knows the Russian language, even though not a single word, taken by itself has any meaning. Many words are ambiguous, and therefore the choice of the required words is possible only in consideration of context. Professor D. Yu. Panov suggests that difficulties arise in connection with the fact that assumptions from the products of creative literature are often very closely related to the very nature of the given language and are deeply rooted in the life and customs of the people. Individual thinking is also "an artistic work" and is very unique.

In spite of the stated difficulties, work continues on automatic translation and there can be no doubt that it will be possible to translate scientific, technical and other special texts. Certain general rules of text
writing, intended for automatic translation, will apparently be used for simplifying the program.

As regards to translation into formal language, the situation is even less encouraging: formal language is poorer than natural language, and therefore it may be said that not all thoughts can be reproduced. This, however, is hardly of deciding importance. The formal language that is required for automated decision making should be the equivalent not of any natural language, but of one specific language with simplified form and limited vocabulary. This eliminates many fundamental and technical difficulties. Furthermore, since military activity takes place in a mass of people with different narrow specializations, the individual linguistic features are smoothed off and equalized. Military thought, despite its dialecticism and diversity, works with specific subjects: troop formations, materiel, terrain, geophysical and meteorological conditions, etc. Finally, formal languages, such as the language of a situation map and language of mathematics, also play an important role in military thought.

These considerations lead to the conclusion that mutual understanding between people and computers can be achieved in the military through specialization of the "military" language, by increasing in it the specific weight of formal elements (display of situation and mathematics), refinement, definition and detailing of concepts, and by developing a special computer language, which in terms of its structural forms will be most suitable for military problems.

Is it possible that a drastic change will occur in "military" language (which, we repeat, is a part of natural language) in the desired direction in the foreseeable future? Bourgeois linguists give a negative reply to this question. For example, Ferdinand de Saussure and his school contend that language is neutral, static, conservative and invulnerable to radical and revolutionary changes. Historical analysis from the Marxist-Leninist points of view indicates that this is not true. Natural language reacts quickly and effectively to social change. Suffice it to recall how the language changed after the Great October Socialist Revolution. Language is actively reacting to the scientific-industrial revolution which we are witnessing. This is manifested not only in the enrichment of the language with new terms, but also in the appreciable refinement of linguistic forms, related to the penetration of recent scientific achievements into society. Science contributes clarity to thinking. This is particularly true of professional language, which should develop rapidly in connection with the rapid change of the means and forms of armed warfare. This development should be directed toward objectivity, specificity and definition.

Let us examine some of the requirements imposed on formal computer language. The problem consists in telling the computer what to do. The language should not be related to a specific type of computer, since this would greatly limit its application. A formal language is constructed from symbols, words, expressions and operators. Symbols are the basic
indivisible elements from which texts are constructed. They include letters (upper case and lower case), numerals, punctuation marks, mathematical symbols, conventional military symbols (tank, airplane, battalion, position), technical symbols (apparatus, stress, etc.). Words are the smallest structural units, formed from symbols, that make sense by themselves. The number consisting of several digits is a word. An expression is a group of words or part of a sentence with independent meaning (an example is a subordinate clause). An operator is a complete thought, complete description of some calculation, specific action or, technical procedure.

There are presently several algorithmic languages that are used rather extensively. In addition there are translators for translating computer programs from one language to another. An effort to make a language as limited as possible in terms of vocabulary and grammatical rules requires that it be oriented toward a certain class of problems. The algorithmic languages used in practice are oriented the same way. The FORTRAN language was developed specifically for solving scientific problems related to the development of physics and technology. The ALGOL language was designed for solving numerical analysis problems. The COBOL universal language was designed for solving commercial problems involving the organization and processing of large masses of data; this language is characterized by the extensive utilization of expressions and operators based on clauses in the everyday English language. There are special languages designed for controlling industrial processes (YaZON* etc.). The LISP [List Processor] language is suitable for writing descriptions consisting of lists of individual objects. It is used for writing interrelated programs, each of which may be included in another as a subprogram.

Mnemonic language is used extensively in industry for the exchange of information between the operators and industrial process control systems. Abstract digital data coding is not the only possible approach; in many cases, particularly when decisions must be made in a very short time, i.e. in seconds or even a split second, it is helpful to use instead a system of coding that takes into consideration the features of the specific troop and technical structure. For example, decision making by the commanders of fighter squadrons and flights, commanders of submarines, naval task forces and air defense units demands such speed of perception and reaction that the use of military language and digital coding may not insure the solution of a problem within the specified time. Mnemonic language is the language of conventional symbols. It has tremendous information capacity but is devoid of flexibility and completeness inherent to natural language. Mnemonic language is suitable for the description of specific actions (if these actions can be predicted ahead of time), for the storage of basic information about the

* YaZON—not identified, but apparently similar to IPC, Industrial Process Control.
state of forces and for retrieval of information. The basic elements (terms) of the language are graphic conventional symbols, each of which covers a whole set of actions, concepts, factors, and logic operations comprising the grammar. A. A. Lyapunov said that any algorithm may be written in the form of a logical schematic by using sequencing operations, and unconditional and conditional transfers. Such grammar is ideally simple. A language of this type is not the language of programming, but only the language of communication between an operator and the technical system.

The alphabet of the language should not be too voluminous, since all symbols must be memorized. Nevertheless it should embrace as completely as possible all processes related to the activity that is being automated. These processes are represented as memory circuits, i.e. series of symbols that represent the various elements and stages of processes. A memory circuit may be used for representing the position of forces, their order of succession in a column and order of entry into battle, structure of a missile complex, etc. Each symbol is fed into the computer and sets into action the program of any complexity. The program generates a series of commands, each of which was not provided for ahead of time, but rather is a result of computations. Accordingly, by combining the mnemonic symbols in a known sequence it is possible to control a weapons system, to issue an operational order or request information.

Formal languages for decision making should be specialized: it is difficult to solve all military problems with one language. The formal language must be made to converge upon the natural military language (the paths of such convergence are found in the COBOL and YaZON languages), and it should also include limited operations with mathematical transformations and computations. Also desirable is good interface with computer languages and with languages designed for solving other military problems (logistics, transportation problems, etc.). This makes it possible to reduce the volume of programs in the special language. An effective method of achieving interlanguage interface is an intermediary language (intermediary translator).

The modern state of the art and theory of computer language is such that questions concerning structure and syntax hardly evoke serious difficulty. The language should have several levels of abstraction, and each level should consist of more general (compared with the low level) concepts and should also be structurally complete. Then each level, being a controlling language (metalanguage) in relation to the lower level, would be suitable for independent utilization (if great detailing is not required).
Chapter 9. Formalization

In the search for the truth the right answers play an incomparably smaller role than mistakes, and a new hypothesis, no matter how absurd, may be more useful than a slight improvement of an existing one.

Poyya

To give definitions that are too narrow or too broad is a mistake, and not an insignificant one.

Aesop

1. Definitions

We will first examine certain primary concepts. Formalization of perception and cognition takes the following path: quality—morphology—ordering—topology—metrics—quantity. We will follow this trail from the very outset.

A method may be effective if it is rooted in a well ordered system of rules and methods that comprise the tools of problem solving. The well-known quotation "Science is born where calculation begins" is completely justified in the military. But calculations are possible only with a mathematical description of situations, action and train of thought. We will consider the various aspects of construction of the mathematical tools.

A tool is constructed in all fields of science step by step under the influence of practical needs. Let us recall the development of geometry: the initial geometric concepts were based on land measurement; later geometry became abstract and transformed into an independent science. But first the needs of land measurement stimulated the development of a tool for solving its problems. Various branches of mathematics, including the very newest ones, are used extensively in the military, but the development of a purely mathematical tool is a very slow process. This retards development of automation, since in the military it is necessary to operate with categories, concepts and objectives which have no analogues in other fields. Therefore, one can rely on borrowing a mathematical tool from the outside to help solve all problems. These problems are still increasing, and we are forced to approach them with intuition, skill and creativity.
Creativity is the highest form of human activity, and this is what introduces novelty to ideas, notions, methods and systems that man masters. During the decision making process creativity plays an exceptionally important role, and we shall return to this topic repeatedly. But to call to creativity in day-to-day life is an unjustified and harmful extravagance. It would be wrong to assume that creative inspiration is essential in all cases of decision making. Analysis shows that the overwhelming majority of decisions do not contain anything fundamentally new or creative. We must disagree with authors who consider each step of decision making, starting with situation evaluation, to be a profound creative act. This is incorrect; indeed if any work is promoted to the rank of creativity (and work invariably involves decision making), then this degrades creativity and creates new unsolvable problems. Not all realms of our ignorance must be concealed by a call to creativity.

In most cases the determination of a method of conduct does not require creative achievement. Creativity is original; it rises above the commonplace. Creativity comes ahead of technology. In order for the result of creativity to be fruitful it must be understood and adopted by many people and this is not always simple. The newer and more profound an idea is, the more difficult it is to accept. There is not enough obedience and discipline. A commander directs many people who are called upon to carry out his will. But before an order can be carried out satisfactorily it is necessary to understand, to sense what must be done.

This takes time, of which there is never enough. The commander, when making a decision, must first consider who will implement it and how. The result depends on the decision and on the quality of execution. It is easier for one to perform a task that one knows. This does not mean, of course, that a decision should be stereotyped, but it should not contain more of the unknown than is absolutely necessary. One should not abuse originality. One should strive to insure that the tool helps to solve as many problems as possible.

Creative search is desirable even in simple cases, but it is not mandatory, and often impossible due to the lack of time. The more complex a problem is, the more stimuli there are for creativity. There are, of course, other stimuli, but a broad range of application is essential. Social benefit is a stimulating factor in any activity that involves creativity. In all probability a new arithmetic and new tool could be thought up for solving arithmetic problems. At one time, this was indeed the case when the decimal system was being introduced. Even now scientists are working on new arithmetic for computers. But having been assigned the task of multiplying two multivalued numbers, should one work on development of new arithmetic or be concerned about improving the number system? Apparently not. It is necessary simply to perform multiplication. It is another matter when we are talking about multiplication or inversion of matrices: this problem may be the source of
inspiration and creativity. Man often makes mistakes, much more often, in fact, than it seems. The first thing to do is prevent mistakes; this requires a method and tool. Creativity must be stimulated. These problems are not contradictory: the less effort spent on simple problems, the greater the possibility for the creative solution of complex ones. Training and experience develop skills and knowledge, and their description is a tool for decision making, which establishes the cause and effect relations between the situation, method of conduct and final goal. The mathematical tool provides formulated dependences, which are largely the result and generalization of experience. The mathematical tool works with abstract problems, but at the same time it is extremely general.

An attempt to expand the range of application of mathematics in certain situations encounters great obstacles. The elements of the mathematical tool are mathematical symbols (plus, integral, equality), and their meaning is precise. In military science, somewhat obscure qualitative categories are sometimes encountered. They are characterized by descriptiveness and flexibility; their boundaries are obscure and they "smoothly" merge into each other. The cause and effect relations are also indistinct. Meaning almost always depends on context and specific conditions.

Thus, the problem consists in formalizing a tool, which the commander and headquarters use in decision making.

2. Ordering

We will recall with what categories, concepts, ideas and objectives the apparatus of military thought operates. For brevity we will use only the word "categories."

1. Ideological and political (the political goal of war, political indoctrination, ideological position, ideological level, ideology).

2. Military (troops, weapons, armed warfare, attack, defense, counteroffensive, rear, nuclear missile attack, barrage, terrain, strong point, assignment of tasks, soldier).

3. Sociological (interrelations, class, composition, social views, social opinion).


5. Technical (aerodynamics, electronics, control, security, excessive pressure, damage, temperature, speed, performance).

6. Geographical and topographical (range, coordinates, continent, boundary, altitude, view, terrain, river).

7. Mathematical.

These categories are used in abstract and specific terms: one may speak generally of an advance as a form of military actions and as a specific aggressive operation. In the former case, man thinks in the abstract and in the latter graphically, pictorially. But abstraction never-
theless requires the use of images with which are connected in one way or another individual concepts and memory. Mental images are multidimensional and dynamic.

The purpose of mathematics is to establish a quantitative relationship between the categories. Sometimes it is difficult to disclose the essence and character of the relations among the categories, although they nearly always exist. This obstacle must be overcome.

The entire set of categories is defined as the space of categories. The space of categories must be organized and the relations and principles in it determined. This is a multisteped problem.

The first step of organization consists in ordering. Ordering is a starting point and logical foundation of formalization. The basis of ordering is experience, both social and personal. Ordering consists in establishing certain relations of order, such as superiority, preference and sequence among the categories. The criteria of order may be:

—Size (a regiment is larger than a battalion);
—Importance, significance, weight (firepower is more important than numerical strength);
—Domination, advantage (of a tank over infantry, nuclear bomb over TNT);
—Sequence (attack after artillery bombardment, shock wave after a light flash, infantry behind tanks).

The relative order, formulated according to different criteria, should not be confused: a regiment, as a rule, is larger than a battalion (ordering by size), but this does not mean that a regiment is always stronger than a battalion (ordering by domination).

Categories may be divided into ordered groups; relations of order may or may not exist between categories of different groups. Ordering is not completely stable. It depends on conditions, on the will of the people and may be changed. One may speak of the probability of maintaining the relations of order.

There are two systems of ordering. The first (Figure 36) is constructed on the basis of previous experience and is valid for average typical conditions. The system embraces practically all categories encountered in military affairs. It is all embracing in this respect.

For certain groups of categories it is altogether impossible to determine typical relations of order; what, for example, may be said about the technical and moral categories in terms of importance or sequence? Experience teaches us that typical relations of order do not exist between these groups of categories. The first system may have several versions for each typical situation. It is the base from which one proceeds when constructing a specific second system.

The second system of ordering pertains to a specific situation. Universal typical ideas are reexamined in light of the problem to be solved. The second system consists of ordered groups, which influence the
Figure 36. First system for ordering of military categories (example).

course of events in one direction. This is illustrated in Figure 37, where the relation of order is established in terms of importance. Certain relations may coincide with typical ones and others may not. The alternative categories in the second system must be ordered. Otherwise the category to which preference should be given will not be clear.

Ordering requires criteria. They are obvious for the first system—a model of generalized experience. Experience is generalized into a theory, socio-political outlook, strategy, operational skill, tactics, and military science. If experience and analysis indicate that it is easier to penetrate the front by attacking at the junctions, then this idea is given preference over other forms of breakthrough. If experience is lacking, the relation of order may not be established.
The starting point for the second system is the first system. The gaps are filled either on the basis of some criteria or in arbitrary order. This is done consciously or unconsciously, and if it is done improperly, then the solution may be wrong: 70% of wrong solutions are the result of improper ordering. It may seem improbable that the great diversity of political, military, technical and other aspects culminates in ordering. But therein lies the power of mathematics which provides capacious and rigorous definitions of complex relationships. We will examine the criteria of ordering. These criteria are also based on outlook, science and experience.

The set of criteria is multifaceted and multileveled. An example is seen in Figure 38. It includes three basic groups of criteria: general, specific and volitional. The general criteria are especially important
in the first system of ordering. They are stable and their change is generally related to significant social transformations, improvement in the technical equipment of armies and analogous large scale factors. Reevaluation of the first group of criteria is always an event of great importance and has grave consequences. To propose and conduct a reevaluation requires (in addition to good reasons) courage and great willpower. The reevaluation of moral categories on the part of Napoleon during his Italian campaign was not perceived for a long time; this cost Napoleon's enemies dearly. The same Napoleon incorrectly evaluated the moral categories in the war against Russia and this cost him dearly. Lenin's strategy of civil war was inconceivable to the overwhelming majority of political and military experts of the capitalist world, who could not understand the reasons for the Red Army's success because their
criteria were wrong. The mass deployment of tanks and aircraft during WWII altered the hitherto accepted order of preference. Partisan warfare was an important factor in the Patriotic War of 1812. Partisan warfare contributed much to final victory over Fascist Germany in the Great Patriotic War. But we should not be surprised at the fact that neither Napoleon nor Hitler's best generals could understand and evaluate the importance of partisan warfare in the overall perspective of war. A factor such as the instillation of automatic control systems also involves reevaluation and ordering of categories.

Each commander works out his own categories as a result of studying military science. Substantiation of the criteria is a task that extends beyond the scope of this work. Nevertheless it is helpful to make some comments on this subject. Models of typical situations (strategic, operational, tactical, organizational), in which decision making is required, should be constructed. Each situation requires thorough examination from the standpoint of the specific content of the criteria. On this basis it is possible to formulate definitions and to establish the priority of the criteria. Are there any unambiguous definitions of any criteria that do not permit different interpretations? By no means always. Nevertheless we daily use undefined criteria for analyzing serious problems.

Specific criteria are related to concrete conditions. They derive from the ratio of forces, purposes of proposed actions, orders of the commander, etc. Specific criteria are essential for the second system of ordering, and although the criteria are related to a specific problem, they may be formulated ahead of time in sufficiently general form. Examples of such criteria are a correspondence of goals and extent of attainment of goals.

Volitional criteria embody the features of a commander's personality but the group factor, training, and membership in a certain military school play the major part. Each commander develops his volitional criteria on the basis of personal experience; they are often more outstanding and successful than universal criteria. When the volitional criteria are perceived by the majority the result is a reevaluation, about which we talked above. Volitional criteria comprise one of the motivating factors of progress in science and art. They may pertain to the first and the second groups and, moreover, contain independent elements. After substantiating a system of criteria, one may embark on ordering.

We mentioned the fact that the method of ordering depends to a certain extent on point of view. Viewpoints may also be ordered. In the final analysis the viewpoint (and the ordering system) which best corresponds to the goal is selected.

3. Topology

The next step in the formalization of the space of categories is the introduction of topology. Topology is just beginning to find extensive
practical application, and new successes can be expected in this field. Topology is becoming an applied mathematical discipline.

Topology is based on sets. A set is defined as a collection of elements of any nature; in this case such elements are military categories. Finite and infinite sets are distinguished; the latter are divided into denumerable sets (a natural number may correspond to each element) and non-denumerable (continual) sets. A set of physical objects (tanks, for example) is always finite. A set of even numbers is denumerable and a set of points on a straight line or plane is continual. Any part of a set is called a subset. Operations of addition, multiplication, intersection and subtraction may be performed on sets. The essence of these operations is clear from Figure 39. A correspondence may be established between elements of sets. A one-to-one correspondence is one in which one and only one element of a set corresponds to each element of another set, and conversely. In multiple correspondence, one or several elements of one set may correspond to an element of another set.

Functions or mappings may be constructed on the basis sets. A function is a certain correspondence between the elements of two sets. A set is ordered if between its elements is established a relation (order) of mutual sequence. Any set whose elements themselves are sets is defined as a system of sets.

In topology the open set concept is fundamental. Any system of subsets of some initial set is defined as topology if it satisfies the following two requirements: the set itself belongs to this system; the sum of any (finite or infinite) number of sets and the intersection of the finite number of sets of this system belongs to the same system. The initial set, with the topology given in it, is called a topological space. All sets that belong to this system are called open sets. Thus, topology may operate with any elements without requiring that the quantitative relations between these elements be determined. One method of assigning topology consists in declaring certain sets to be open. The physical meaning of an open set consists in the fact that each element of the set has neighboring elements.
that are similar in some sense and which also belong to the set. Such nearby points are called a **neighborhood**.

Suppose that we are examining a set of military categories and we want to apply to the set a system of views, constraints or relations. If a concept of neighborhood is defined (in the literal sense), we may select such elements of this set that it will be open. Otherwise there is a risk of entering into a different range of categories with different properties, or of not exhausting our range. After substantiating the open sets we may form a topological space. The concept of open set paves the way for proving quantitative relations between the categories.

**Base** is an important concept in topology. The base of a topological space is a set of open subsets such that any other open set may be represented as the sum of these subsets. In a sense the base contains these simplest subsets which can be used for making all other subsets. This is equivalent to the development of the basic reference units from which all others may be constructed. The base should be finite or **denumerable** (and not **continual**) and the base elements (the simplest groups of categories) should be separable from each other and should not run together. This simplifies the justification of mathematical operations in a topological space.

A feature of the topological space is the fact that the concept of distance between points (in contrast, for example, to geometric space) does not exist in it, and the relation between the points is established on the basis of other principles. Sometimes topology is called “elastic geometry”, since the objects in topological space may be blown up or compressed in various parts as desired, but they remain unchanged; the only thing that is not permitted is cutting or joining together. From the standpoint of topology a dumbbell, coffee pot and doughnut are identical geometric bodies. The use of topology may be beneficial in cases when distances are not important, but relations, in particular for analyzing various structures and for transformation of some structures into others, are important. We can see the analogy between topological space and the space of real numbers. This analogy helps us to penetrate into the crux of the matter. In topological space we work with sets, and in the space of real numbers we work with numbers. The base of topological space may be denumerable, i.e. a natural series of numbers. Any part of a topological space with a denumerable base may be represented as the sum of base elements, and any whole number may be represented as a sum of natural numbers. This essentially means that we work with individual categories (points of topological space) and sets (groups) of categories as numbers. The difference is that the distance between the elements of topological space, in contrast to number space, is not defined. But topology operates with elements, which are themselves sets, and consequently may exhibit a variety of properties. This is useful in describing military problems.
Each point of topological space may represent one military category. A group of categories represents a part of topological space, containing some set of categories, “points”, belonging to this group. Let us assume that we are discussing a group of categories such as combat readiness. Combat readiness is described by a set of characteristics and properties. The number of such characteristics may be finite or infinite. Each characteristic is itself a category, and we will view it as a point. After locating this point we must determine its interaction with other points of the topological space. The topology describes this interaction.

Let us examine the structure illustrated in Figure 40. The rectangles designate certain categories, and the lines are the connections between them. For example, troop formations, technical systems, headquarters branches, reports about enemy actions, the personnel of a command post, algorithms and so on may be rectangles. The lines represent any form of communication, interaction, counteraction, competition or sequence.

In making organizational decisions it is very important to have the capability of quantitative evaluation of the properties of the structure and of quantitative characteristics related to its transformation and to other structures. Topological transformation is defined as the breaking of some connections and establishing new ones. If the connections are not changed there is no transformation from the standpoint of topology. Topology makes it possible to investigate structures, evaluate the complexity of transformations and establish the relations between the structures. The topology of structures determines their practical properties.
No less important is the use of topology for investigating configurations. Let us assume that we are examining a system of roads. It can be improved by building bypasses to insure the movement of traffic without congestion. In other words, the decision must be made concerning the creation of a certain road configuration, and this may be done with the aid of topology.

The range of application of topology is somewhat different in operational decision making. The military categories (including ideas and concepts) may be represented as structures or configurations and topological spaces may be constructed. One form of topological space is quite close to the usual metric space, i.e. to spaces in which distance is defined (and may be measured). These are the so-called Hausdorff spaces, in which any two points have non-intersecting neighborhoods. This property means that the points are separable from each other. Hausdorff spaces (especially normal spaces, in which any two non-intersecting closed sets have non-intersecting neighborhoods), are best adapted for the construction of quantitative relations.

The better organized the space categories are, the easier it is to prove the functions and functionals that express the correspondence between the various categories and groups of categories. This leads to quantitative dependences, despite the fact that there was no quantitative difference in the initial space of categories. An expression for the functional of effectiveness of a military decision can be formulated in topological space.

4. Metrics

The next step of formalization is introduction of metrics, i.e. the establishment of the distance between categories. While order determines relations of the types “larger–smaller”, “stronger–weaker”, “more important”, metrics makes it possible to establish how much larger, stronger, or more important. For example, the weights of objectives, if they are cities, may be designated in accordance with their population. This means that we mapped a non-metric “space of objectives” in the metric space “population.” The success of a military operation is often evaluated in terms of the destruction of manpower and technology. This is also metrics.

It is sometimes wise to discuss the extent of fulfillment of a task, to introduce several gradations and to assign a number to each of them. A sum total of these numbers may be used as a metric. One may examine the probability of solving a problem and use this probability measure as a metric. One may establish the “distance” between problems, i.e. the reason for introducing a more general and common metric to these problems. For this purpose, it is necessary to determine the conditional probability that a certain more general and common problem will be solved if the specific problems are solved.

Direct metricism is sometimes possible. Take a category such as the
vigilance of the troops. This category may be evaluated quantitatively on the basis of information about the change of state of the enemy, which a military unit gathers in its sector. The metric here is an informational one. One means of mapping categories in a metric space is the use of the so-called monotonic intermediary. One has in mind the situation when two or more incommensurable (or immeasurable) categories are dependent on the same metric category. For example, such categories as vigilance and combat readiness may be related under the appropriate conditions to the number of troops. As the numbers increase, these categories also expand. In this metric it is impossible to arrive at an actual evaluation of vigilance (if this could be done, we would not have to use the monotonic argument), but this is not always required.

The most common metric is effectiveness. Effectiveness criterion expresses the extent of goal attainment (the amount of enemy forces destroyed, damage inflicted or prevented). The mathematical dependence between effectiveness and the categories that are to be metricized is established. The change of effectiveness that occurs when one category is replaced by another is used as distance.

Such are the basic concepts of formalization. To prove that this is not fantasy, let us look at the following example:

A commander receives a new assignment. He is not familiar with his personnel and to facilitate familiarization with his new assignment, he intends to use personal contact as well as modern information systems and mathematical methods. The basic category to be thoroughly analyzed in the first step of the operation is the subordinate. This is an element of the broader category of military serviceman. In a mathematical sense, a set of subordinates comprises a space that needs to be described. Familiarity with the subordinates makes it possible to establish the initial ordering, the criteria of which may be service rank, party affiliation, qualification (education and experience), service decorations, etc. As familiarity with subordinates increases, ordering is refined. Here not only individual subordinates, but also units (subsets) are subjected to ordering. Ordering makes it possible to solve certain problems mathematically, for example, to write work schedules, distribute resources, etc. This is the initial and roughest mapping of a space of categories into another space, in which calculations may be done. The next step is topologization. There are two possible variations here. The first is formal. It is necessary to assign a system of subsets (groups of subordinates) that includes the following: 1) the entire set (the entire formation); 2) any sum of these subsets (groups of people); 3) any finite intersection of these subsets (groups of people that simultaneously belong to different groups). The subsets that belong to this system are open subsets.

The second method of introducing topology is conceptual and informal. Some subsets of subordinates must be declared open. They may
be the following: groups of subordinates with similar service rank, specialties, military experience, education, socio-demographic backgrounds, etc. The meaning of openness of these sets is expressed by the word similar (these are groups which may be reinforced, and altered and in some cases do not have distinct differences). The declaration that certain sets are open is the introduction of topology.

It can be shown that the construction of topological space in this fashion is a "Hausdorff" operation. The neighborhood for each element is comprised of people belonging to the same group. For any two people it is possible to select non-intersecting neighborhoods, i.e. the closest circle that is not a circle for other persons. No mathematical meaning is ascribed to the criterion according to which the neighborhood is selected. The space thus formed may be normal if any two non-intersecting closed subsets have non-intersecting neighborhoods. This condition must obviously be satisfied if there are no closed groups (the latter of course, is inadmissible).

We will introduce the base. The base elements may be the smallest (in numbers) subsets of persons capable of performing certain military or training functions or who have a certain level of training. Any subset of persons viewed as an independent element in the solution of the corresponding problem should be expressed through base elements. Topology may be introduced by means of a base. The reduction of a space of subordinates to a normal topological space with a finite or denumerable base makes it possible to solve complex problems, especially effectiveness evaluation problems.

And, finally, the last step is introduction of a metric. A metric may be constructed by mapping a topological space into a functional space (effectiveness) by introducing weights for open subsets and for elements of these subsets, or by any other means. The entire potent tool of computer mathematics may be used in a metric space.

Further definition of the example would require mathematical calculations, but there is no need for this: we are discussing the fundamentals not solving specific problems.

Here we must caution against a "formal" approach to formalization. Formalization has one purpose: to make calculations possible. But, in approaching formalization as well as determining the range of application of calculations we must proceed from the tenets of the Marxist-Leninist philosophy and Soviet military science. Mathematics is a powerful tool, but nothing more.

5. Development of Categories

We will evaluate the real capabilities of the formal tool. The use of topological or metric spaces is aimed at functional description of the problem (i.e. dependence of the result on the properties of a situation), expressed by military categories. The question arises as to whether
difficulties in formalization are related to poorly developed speech categories, their lack of definition, incompleteness, and unsuitability for quantitative expression. Consequently, categories must be developed. This is, in all probability, one of the chief problems encountered in the adoption of automation. We will attempt to formulate it.

All information that pertains in one way or another to the activity of the commander and his staff may be represented through some set of ideas, variations and the like. Ideas and variations are formed from objectives, categories and concepts. We will recall that an idea is basic thought, significance, and importance formulated in general form. A category reflects the most general and important properties, aspects, and relations of phenomena in reality. Concepts describe and generalize the most essential attributes of phenomena and processes, and they comprise the meaning of the words in language. Concepts are more flexible and progressive. Thus, an idea, category, or concept comprise the hierarchy of generalizations, in which any thought can be expressed. These categories are not complete and do not accurately reflect the essence of military situations and their consequences, which limits the productivity of thinking, intercourse and instruction. The development of categories is an important aspect of the development of any science, particularly an exact science. Formalization—the mathematization of science—requires formalization of categories. It is impossible to imagine the development of a mathematical theory of functions without a precise and unique definition of such categories as set, function, correspondence, uniqueness, limit, convergence and variables.

Less attention has been paid to the development of military categories. Just try to find a definition of such a category as military organization in the dictionaries and textbooks. The discrepancy is great indeed. Military categories are so complex that they pertain to social (moral-political state), scientific (effectiveness), and technical (everything related to the characteristics of weaponry) categories and are themselves, in part, special categories. The formal relations among the categories cannot be established "by definition" (the same is true for mathematical categories).

The main trends in the development of military categories are listed below:

—Detailing;
—Refinement of content (meaning), definition;
—Metricizing;
—Formalization of relations;
—Establishment of hierarchies;
—Generalization;
—Development of new categories;
—Evaluation of the completeness of categories.

These trends are mutually related. We will comment briefly on some of their content.
Detailing is required for the organization of thinking and for entering into a systematic mainstream. Consider a category like combat steadfastness. It is applicable to any unit, from a solitary soldier to the armed forces as a whole. Such generality is extremely useful in certain cases, for example when it is necessary to impose requirements for adhering to principles of personnel training. In other cases, generality is harmful. It is impossible to give an exact definition of generality without placing restrictions. Therefore a definition does not exist and hence formalization is impossible. The way to solve the problem is to break the category down into simpler ones that can be exactly defined. This is called detailing. One possible variation of detailing of a category is represented as a diagram (See Figure 41).

It is possible that an all-embracing and complex category such as moral state can one day be detailed in like manner. Subcategories can be introduced and examined here: Demographic composition, social profile, Party-Komsomol participation, combat experience, class group, personal interest (in some activity), negative factors, etc.

Detailing of military categories is an important and complex problem that requires comprehensive analysis. Superficial, simplified, unsub-
stantiated application of quantitative evaluations is absolutely inadmis-
sible. The results of detailing should be checked repeatedly and carefully
before they are put into practice.

Let us turn now to definition. Detailing facilitates definition. Refine-
ment of content should be based on practical experience and clear under-
standing of future goals. All categories are developed in consideration of
past experience. But historical collisions are always specific and are tied
to a specific evaluation; therein consists one aspect of definition of cate-
gories.

The human mind is incomparably more flexible than an automaton.
Man freely orients himself in semantic fine points, and if necessary he
can explain how to understand and use a given term (sometimes a few
words are sufficient for this purpose). Flexibility has its price: its
antithesis is outright arbitrariness and error in the usage of categories
and in conclusions. Automation requires a one-to-one correspondence
and unique definition, but then errors are not permitted.

Let us examine the "initiative" category. The Dictionary of Russian
Language (1957) defines it as follows: "1. initiative, stimulus to under-
take some activity . . . 2. enterprise, capacity for independent actions."
The ambiguity of interpretation becomes obvious when we compare it with
the "arbitrariness" category: " . . . willful, unwarranted doing of some-
thing." "Independent actions" are independent because they were not
anticipated beforehand. It turns out that the dictionary definitions of "ini-
tiative" and "arbitrariness" are not very different?! The fact of the matter
apparently is not simply that definitions do not reflect all semantic
details. The reason for this goes deeper: there is no distinct boundary
line between certain categories; the boundary line is displaced in one
direction or the other, depending on the specific situation. Nevertheless
the overwhelming majority of people correctly perceive the difference,
although confusion is not excluded.

We will define "initiative" as independent action that is not contrary
to an order and is aimed at reaching a positive goal. The combination
of "independence" and "not contrary to an order" reflects the semantic
spirit of the word "initiative." The qualification: "attainment of a posi-
tive result" further defines the boundaries and guides us onto a quanti-
tative "course of effectiveness." These three criteria, "independence,"
"non-contrariness" and "positive result" are equivalent to mathematical
discreteness, which keeps one category from changing into another, which
in some way similar, but in another way opposite. The formulation may
evoke some objection, but we use it only for means of illustration.

Let us turn now to formal description of categories. Most military
categories (but not all) yield to metricizing. As we have already men-
tioner, metricizing begins with ordering. The simplest method of order-
ing is to establish gradations; for example, 10 gradations of "combat
courage" and "initiative" may be established. We become accustomed to them in practical activity and use them as a measure. Examination points are another means of introducing a scale of measure. Long-standing social custom enables us to become accustomed to this measure, even though it is very conditional. Further, a segment of the number axis may be compared with the scale of gradations (points), and continuity, useful in functional transformations, may be assured. Of course metricizing should be done carefully. The absolute weight and relation between gradations may change, depending on the situation, conditions and random factors.

Metricizing of categories should reflect the flexibility of our concepts. Captain Tushin in Leo Tolstoy’s "War and Peace" was a courageous energetic officer with great initiative in battle, but he was completely meek and even rather stupid in his relations with his commander whom he feared and did not understand. Tolstoy forces us to understand and sense this, but how does one make a computer understand this without using a lot of information? In order to do this it is necessary to examine the relationship between a given category and other categories, especially those that describe a military objective, effectiveness, usefulness of actions or processes. It is necessary to analyze whether or not the content and evaluation of categories change, depending on conditions, and if so, then how? Can regularity or order be found here? The search for natural laws in the space of categories and the dependence on external conditions are the main guidelines used in metricizing and formalization.

Having introduced metrics we may proceed to the formalization of the contents of a category. Formalization presumes the establishment of mathematical dependences between the quantitative expression of categories and external conditions. Formalization is the concluding step in the substantiation of a category, after which it may be calculated and operations may be performed on it with the aid of technical systems. Formalization sometimes compels us to reject several properties of categories and thereby narrows the range of applications. But such is the price of success.

Formalization of relations between categories requires a single scale of measure for a whole group of categories. Formal definition of each category individually facilitates the introduction of a common metric [scale of measure].

The hierarchy of categories is established after the relations between them have been formalized. Within each category a hierarchy occurs in accordance with the detailing that was accomplished. The hierarchy, reflected in the structure of military concepts, may also be constructed in the overall system of categories. New generalizations may be derived on the basis of the hierarchy of the categories. If we find that some aspects of military activity are encompassed by several categories and that this group of categories is stable, then we make a generalization.
Here a new heading appears, but not a new category, of course, since
the generalization does not reflect any new properties, characteristics or
aspects of military activity. Its usefulness consists in its great information
capacity, and consequently in economy. We will use as an example the
term “military industrial potential.” The purely military capabilities of a
state, reflecting the quantitative and qualitative makeup of the army, and
the quantity and quality of weapons, are characterized by the “military
might” category. The state of industry, its productive resources, raw
material base, correct relations among the sectors of industry, independ­
dence from foreign sources, training of workers and engineers, etc., are
usually called the “level of industrial development.” The category “man­
power resources” describes the size of the population, its distribution by
age groups, educational qualifications, ideopolitical unity and national
composition. To encompass the combat capability of the army, its capac­
ity for reinforcement and material-technical supply for a long period
of time, the term “military-industrial potential” is used. The word
“potential” is used in the sense of “resource,” “capability” with the
emphasis on the future. A quantitative measure may be found for some
additional development.

The formation of new categories involves the development of weap­
onry, military doctrine or operational skill. Such categories as “nuclear
warfare” and “global warfare” arose in connection with development
of nuclear weapons. The categories “escalation of war” and “small wars”
(in their contemporary meaning) are related more to the old traditional
methods of warfare, but they reflect new trends in application. The de­
velopment of new military categories is an important problem in military
theory. For example, a phenomenon (in the above mentioned sense)
that has not been defined is the capability for military resistance pro­
longed for many years, which changes into active and successful actions
on a strategic scale. The expression “temporary military advantage” is
obscure. How does one interpret the term “temporary,” in what sense is
the word “military” used, is the purely military aspect actually intended
or is it compounded with another one, what is the nuance of the word
“advantage,” and in particular should capture of territory always be con­
sidered an “advantage” or should some more precise word be used? This
expression is obviously based on undefined categories.

The question of the completeness of military categories is an inde­
pendent topic. In order to describe a situation and formulate the data
required for decision making it is necessary to use categories with a cer­
tain composition. Whether or not the available data are sufficient cannot
be determined ahead of time. The same main factors come into play
even in very different situations, but in order to discover them it is neces­
sary first to describe the situation for which purpose a certain set of
categories is required. The result is a closed loop. We encounter the
same problem in other fields, mathematics in particular. Scientific and
technical problems are now so complex that it is often necessary to start solving a new problem by developing terminology and apparatus. Categories should be developed in consideration of their use in automated systems. Intensive research is now being done on the formalization of this problem, i.e. on the development of programs for computers capable of developing new categories (especially new concepts) on the basis of analysis, sorting and classification of data.

Figure 42. Program for the formation of concepts.
One system for developing concepts, tested and used for compiling reference tables on the basis of raw data, and also, according to the authors for "classification of political and sociological data, and for analysis of medical data"\(^1\) is shown in Figure 42. Two processes are carried out in the system: explanation of what is important for the description of a given category and explanation of how substantive this is.

The development of military categories should be undertaken on a modern scientific and technical basis. New categories will materialize along with the development of military science and weaponry. The use of automation will reveal deficiencies in the definitions of categories. At the same time, a theory should be developed for evaluating the completeness of the description of military problems and formation of new categories. The scientific base for the formulation of a modern military-mathematical system should be developed in the context of dialectic contradictions and unity of these trends.

\(^1\) Programs for Computer and Abstract Thought, *Elektroniks* (Electronics), No. 16, 1970 (Russian translation).
Chapter 10. Theory of Operations

*What does “give a definition” mean? This means to express a given concept as a different, broader one.*

V. I. Lenin

*Each problem I ever solved became a pattern, which I used later for the solution of other problems.*

Descartes

1. Factorization

The questions to which this chapter pertains have a rich mathematical and applied literature. Our task is to evaluate the range of application of various mathematical methods in the decision making process.

Mathematics is required: a) for formal constructions of the hypotheses of decisions; b) for quantitative analysis of the validity and truth of the hypotheses, derived both formally and informally (heuristically); c) for evaluating the effectiveness of hypotheses for precisely defined conditions or in a range of conditions; d) for optimizing the initial hypotheses.

The set of mathematical methods for solving complex problems, such as industrial, military and economic, is combined under the heading “operations analysis.” Operations analysis is characterized by a systematic approach, which takes into consideration the relationships and mutual dependence of the component parts of a problem. The systems approach to problems cannot be strictly formal: formalization is helpful only at a certain stage of the operation. We have discussed the “pre-formal” stage. In this chapter we will be interested basically in the mathematical aspects, including data processing.

A formal approach should satisfy the following requirements:
—universality, stability, and independence from circumstance and conditions;
—uniqueness—should produce unique or equivalent results that satisfy the initial data;
—computability (recursion).

The formal approach should be axiomatic; it is not related to the meaning of the concepts in which the problem is constructed. Formal
mathematical methods have a rich and illustrious history; they have played and continue to play the leading role in engineering, though their range of application in an analysis of social processes was narrow in the past. The reason for this was the complexity of the statement of problems and the unwieldiness of computations. Such computations were not feasible before the invention of the computer. The development of computer technology became the material base for the extensive adoption of mathematics in the military.

Military situations are complex and to describe them requires many parameters, the number of which may reach tens and hundreds of thousands, and sometimes even millions. It is very difficult to become oriented toward such a large number of parameters. Therefore, simplification is done and a model is constructed which reflects the basic, determining aspects of the problem but is described by a much smaller number of parameters. Not all parameters have an equal influence on the course of events, and most of them may be omitted without loss. The main determining parameters are called factors. If one knows the factors ahead of time, then one may direct his energies to their determination and work just with them. Sometimes it is possible to determine or guess most of the factors on the basis of experience. But this involves some risk: one may place too much reliance on experience and "throw the baby out with the water."

The branch of mathematics that tries to reduce the size of problems is called factor analysis. To enable the reader to more clearly imagine the essence of factor analysis we will present the following example. We cannot directly measure such important characteristics of man or organization as work capability, efficiency, responsiveness, discipline, moral stability, activity, and creativity, which may be included among factors. But with data about behavior it is possible to find answers to questions (tests) written in a certain way in which reactions to different inputs are reflected. These answers (reactions) are measureable parameters, which by themselves are not always of equal importance, but they may be used as the basis on which to judge factors. The problem is to find the numerical values of the factors (on the assumption that the units of measurement have been established) or to determine their composition (if the units of measurement have not been established). The mathematical foundation of factorization is the fact that observable parameters, which depend on a given factor, are strongly related to each other (mutually correlated). If all the parameters can be divided into groups, within which there is a strong relationship among the parameters, then it may be assumed that each group of parameters describes one common factor which most strongly influences all the parameters of the given group. For all the dependent (correlated) groups of parameters that are found there will be as many factors. Factor analysis makes it possible to solve this problem and discover the main and concealed
elements of a situation, the manifestation of which is hardest to ascertain.

There are two variations of the statement of the problem of disclosing factors (factorization). In the first variation the factors are known but their relationship to the measured parameters is unknown. It is necessary to find the values of the factors. In the second variation neither the factors nor the method of their measurement are known; it is necessary to find the factors, determine the units of measurement if a quantitative measure exists, and to find the values. In routine discussions we usually work with general factors which are predetermined. Factorial human thought is not simply an acquired (during education) property but a psycho-physiological necessity, since it is impossible to mentally encompass all parameters at the same time. Many thought processes are based on factorization. No two maple leaves are exactly alike, but nevertheless we correctly identify a maple leaf. How is this done? There are recognition factors: outlines, color, density; there are few such factors, and they are characteristic; the combination of these factors for maple leaves is always identical and different from oak leaves.

Factorization is a subconscious, intuitive process. But the capabilities of intuitive factorization in complex unusual conditions must not be overestimated. What factors influence modern warfare in general? And what factors influence the specific battle or specific conflict? Intuition and experience do not suffice for the right answer; a formal approach is required.

Let us discuss the first version of factorization and examine an organizational decision. We will assume that we are required to create an organization for performing certain prescribed functions. We construct a model of the organization. The basic factors are known: they derive from the purpose and functions of the new organization. The factors, for example, will be productivity, operational capability and economy. The factors are computable: productivity may be described by a function, operational capability is expressed by the amount of time spent on the performance of typical work, and economy is described by the consumption of resources (manpower and material). We write a list of parameters that describe the elements of the structure and connections: the number of inputs and outputs of each element, the time required for processing a given amount of information, time of reaction to external stimulus, transmission capacity of the connections, information time lag in each link, etc. We assume that the number of parameters by which each element or each connection is described is five, the total number of elements in the structure is 20 and the number of connections is 20. This structure corresponds to a very small organization; furthermore the number of parameters here is 2,000. But even though the number of parameters is large, they as well as the relationships between them may be measured directly and evaluated. First we must express with sufficient accuracy each parameter through factors. Parameters are represented as a sum, in
which each term is the product of a coefficient ("factorial load") and the corresponding factor. Then we must find the coefficients, the factorial loads. For some of the factors the load will be zero (the parameter does not depend on the factor). Knowing the parameters and the factorial loads we may solve the inverse problem: find the values of the factors. Description of the organization through numerous and interrelated parameters is replaced by factorial description; this means that certain characteristics of productivity, operational capability and economy will be ascribed to the organization.

A decision concerning the applicability or inapplicability of a variation of an organization is made on the basis of factorial description; the correctness of the decision depends on the accuracy of factorization.

In the second version of the problem, the factors are unknown. They are determined according to the degree of influence on the parameters. Groups may be taken from among the parameters which react especially sharply to a change of each factor individually; it is natural to assume that these parameters are strongly interrelated (a change of one parameter is accompanied by a change of another). All measured parameters, on the basis of this assumption, may be broken down into groups, within which the mutual correlation is strong, but weak between the groups. The parameters are grouped on the basis of the correlation (covariation) matrix of the parameters, which takes into consideration the relation among them. A method involving the determination of the maximum value of some function, which depends on the factors and method of parameter grouping, may also be used. When a group is constructed the factor is found as a value which most strongly correlates with the parameters of the group. The number of factors is apparently equal to the number of groups. A simplified geometric model of factorization is described as follows: We represent each parameter as a vector in some multidimensional space (Figure 43). Then all the parameters of one group form a cluster of vectors. A change of one of the vectors has a strong effect on the others. We find the summary vector of the cluster. Since its length and direction are determined by all parameters of the group, it may be considered as a factor. It is clear from Figure 43 that the set of parameters is replaced by two orthogonal (and consequently independent) factors.

It is not only very important to formally determine a factor, but also to give it the correct interpretation, to understand its internal essence and to determine it as an independent category. Factor analysis is only a link in the complete chain of considerations. If the factor as formally determined is not substantive, then it cannot be used. The features of the decision making method are manifested most clearly here. On the one hand, maximum formalization is desirable in order to express the categories in numerical form. On the other hand, since computations are not the only (and not the main) form of military thinking, it is neces-
sary to determine the literal meaning of the categories with which it is necessary to work.

As soon as the factors are determined, the factorial loads and errors of the factorial model are found. The last step is evaluation of the admissibility of the resulting approximation.

As an example we will discuss the preparation of an information decision on situation recognition. The number of parameters that describe the situation is so large that evaluation is difficult. Therefore, it is necessary in problems of this type to use two-step factorization. The first step consists in the selection of the parameters which can be measured, computed and considered in general. The number of such parameters should correspond to the actual data processing capabilities. This is factorization. In principle this factorization is no different from the one examined above. But it is impossible to use the method of factorization in pure form since we want to avoid processing the entire flow of input information. If the basis of factorial analysis is the relation among the parameters, then here (in the first step of factorization) it cannot be taken completely into consideration. The existing parameters are selected on the basis of rules that are established experimentally. All the parameters found in the input information are initially classified in terms of reliability, relevance to a specific situation, magnitude (weight, significance),

Figure 43. An example of factorization.
newness, unexpectedness, correspondence with the required solution, etc. Selection criteria are introduced. The criteria may be mixed: the parameters that correspond to several criteria, such as the level of reliability and the degree of newness, are selected. The formation of the group of parameters, on the basis of which situation recognition will be accomplished, is completed by refining the content, units of measurement and magnitude. From among the other parameters that are to be discarded it is advisable to extract some small fraction of the ones that are closest to the existing (selected) parameters for control. These parameters are called check parameters. The second step of factorization is to determine the most important factors of the situation. These are factors that determine the state of the troops (ours and the enemy’s), and possible development of events and outcome. The procedures for the second step are the same as for the first. It may turn out that an error was made in the first step and some important parameters were discarded. Then the result of factorization will be incorrect. In order to control this, check parameters are used and the procedure is repeated. If the new result does not differ significantly from the previous one, then the first step was done correctly. Nevertheless there is a risk that an important parameter will be concealed and discarded in the overall mass of unimportant ones. One guarantee against this is mandatory inclusion of atypical, new, unexpected, unusual parameters among the substantive ones in the first step of factorization. How important they are will be shown by the second step. The strength of factorial analysis lies in its formality. But therein also lies its weakness, which, however, should not be overestimated: surprises that are difficult to detect occur very rarely in mass situations.

There is yet another effective method of reducing the number of parameters. It is known as aggregation. Several parameters are combined into one function, and then a few functions are used instead of a set of parameters. The reverse transition is done in some step. A condition for aggregation is that the solution [decision] must be dependent on the combined functions.

2. Hypotheses

Variations of decisions, which we will call hypotheses, are developed on the basis of a factorial model. It is said that a space of situations is mapped into a space of hypotheses. An hypothesis may be derived as a result of deduction, assumption, or guesswork. If the makeup and number of attacking enemy troops are known it is possible to establish the number of troops that will ensure defense. The starting point here is some a priori known relation between attacking and defending forces. The relation may be expressed functionally. The construction of mathematical functions is based on a set of real numbers; both the input data
and the final result are expressed through numbers. We have seen that many military categories do not have a numerical expression and sometimes do not yield to ordering. This does not mean, of course, that situations described by such categories cannot be mapped into a space of hypotheses. A nonformal hypothesis is also mapping. Formal mapping requires methodology.

An effective methodology is mathematical logic. The basic feature of logic functions is the fact that the elements of situations and hypotheses are in general not related to numbers: a symbol may be ascribed to them. A list of all symbols is called an alphabet, and an undefined symbol, which may be any element, is called a logic variable. We will assume that a logic function depends on \( n \) independent variables, and both the variables and the function acquire their own values from a two-element set: 0 and 1. We construct a table, in which there are \( n \) rows and \( n \) columns; each column defines one of the possible combinations of \( n \) variables (Table 11).

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>( \cdots )</th>
<th>( n-1 )</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( \cdots )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( n )</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The table describes a logic space, and each box of the table describes one of its points. The logic functions in this space may be counted and numbered. Each symbol is one of the values of a logic variable. There are two types of logic, discrete logic in which the logic functions acquire a value from finite sets, and continuous logic in which continuous (continuous) sets participate. The concept of validity is most important. In two-valued logic it has two values—true and false; in many-valued logic it has a finite set of discrete values from one to zero; in continuous logic—an infinite continuous set of values in the same range (one—true, zero—false). The two-value logic has undergone the greatest development.

In information decisions we are interested in the validity of the description of a situation, and this means that situations and hypotheses consist of the same elements; they are one and the same set. An hypothesis
in a given case is a certain mapping of a set on itself. The logic function in such mapping is called uniform. In organizational and operational decision making a set of situations is mapped on a set of behaviors; this is a qualitatively different set; the logic function is called nonuniform. In uniform logic functions a set with elements—true statement and false statement—is examined, and this method is called propositional calculus. The logic variables that are found in nonuniform functions are called subjects and the functions themselves are called predicates. Two more operations, called general quantifier and existential quantifier, are used in predicate calculus. In the operator of the general quantifier, the logic function is equal to unity for any logic variable, and in the existential quantifier it is equal to zero for all logic variables.

Logic operates with simple and complex (compound) statements; the latter are formed by means of logic connectives. The connective “and” (cold and raining) is called a conjunction, “or” (snow or rain) is a disjunction, “not” is negation, “if . . . then” (if it is raining, then it is wet) is implication, “if . . . and only if . . . then” (if A is true, then B is true, if A is false, then B is false) is two-way implication. These five connectives are sufficient for the construction of complex logic expressions.

Formal logic transformations are proved in Boolean algebra. Boolean algebra is defined as a set and two operations: union and intersection satisfying certain axioms (associative, commutative, distributive operations; presence of zero and identity elements; presence for each element of a set, union with which produces one and intersection with which produces zero).

In the old problem it is required, using one question, to explain which of two roads lead to a goal; here the answer (“yes” or “no”) may be true or false. The situation seems hopeless, but this is not the case. A question in the form of a simple statement solves nothing, but the use of a complex statement solves the problem. After having made a truth table for simple and complex statements and after having asked: “Will the answer be true to the question as to whether this road leads to the goal?”—we shall easily find that the answer “Yes,” indicates that this road is the correct one, while the answer “No” is false, regardless of the truthfulness of the answer.

Dialectic logic offers new possibilities for the formulation of hypotheses. This term was introduced by Hegel, and with it he entitled his idealistic treatise on the laws of development of all “natural and spiritual things.”

V. I. Lenin did not take the term “dialectic logic” to mean a science that was special, independent or different from dialectical materialism. Some scientists view dialectical logic as part of the theory of recognition of dialectical materialism.¹

¹ See N. I. Kondakov, Logicheskiy slovar’ (Logic Dictionary), Moscow, Nauka, 1971, p. 128.
In this section we will use the term *dialectical logic in the strict mathematical sense*. Mathematics, like any other science, was developed dialectically. This is not always recognized; the great mathematicians of the past were fundamental dialecticians. But mathematics did not have in its arsenal a general method suitable for direct description of the dialectic essence of specific processes. A new field, called *mathematical dialectic logic*, is now being developed. Its essence consists in the direct utilization of the laws of dialectics in mathematical operations on symbols or numbers. This requires the construction of the corresponding mathematical transformations, and through them the expression of physical phenomena.

Threshold transitions are fundamental in dialectical logic: after reaching a threshold value, a variable is transformed or gives rise to one or several other variables. Dialectical logic still lacks rigorous axiomatics. The future will show how fruitful and all embracing is the formalism of dialectical logic. More than once, promising mathematical ideas were not used and died, while other, which at first glance were less effective ideas, acquired surprising importance. In this case the important factor is reality—relevancy to nature and to real life situations—which is inherent to dialectics in general; this gives rise to optimism.

The next method of formulating hypotheses consists in *heuristic programs*, which must reproduce certain basic elements of the course of human judgments.

Earlier we examined certain possibilities of heuristic programs in problem solving. We speak here about advancing hypotheses. This is only a part of the overall problem, simpler and less important, and closer at hand and more promising from the standpoint of computer heuristics.

Heuristic programs essentially differ from any formal (especially logic) program only to the extent that they are based not on the widely accepted “legitimate” axiomatics, but rather on individual axiomatics, and in most cases not completely acknowledged. A program itself is the corollary to an axiom, although the method of deriving the corollary is not always clear. Perception and explanation of given events, facts, ideas and considerations are diverse and subjective. Similar solutions are given for very different and often contradictory evidence solutions. The approach to the solution of problems is just as diverse as the temperaments, characters, sympathies and experience of people; in order to uncover the fundamental, nodal points it is necessary to penetrate into the depth of a process. We cannot agree with the opinion of certain specialists that the quality of each specific program is limited to the competence of the programmer and the modeled subject. The difficulty is that neither the author of a program nor the analysts after him can explain how a leading idea appeared (and sometimes even who advanced it); it came about intentionally or randomly.
The fundamental question about an heuristic program is the question of its existence: does a program exist that is suitable for some group of problems, or is each problem solved by its own special program, not resembling any other? Experience shows that there should be either a general heuristic program or a "programming program," which develops a program for the solution of a specific problem. As regards a single program for the solution of a wide range of problems, its existence is doubtful in most cases. It is important to know whether or not there is a programming program. Without such a program training is impossible.

Even though ambiguous (imprecise) problems are understood and solved variously by different people, this does not interfere with the working out of solutions on approximately the same qualitative level and within the same period of time. The method: one "thinks out loud," another writes a program—is not construed as the only promising method; the deeper the mind, the more complex are the stimuli. Heuristic programs should be developed by the commanders themselves, and hopefully the outstanding military leaders work on them and mathematicians assist them, and not the other way around, as is now the case in order fields. The basic ideas of a heuristic program should be worked out by the same man, and their development and implementation should be entrusted to a qualified group. Improvement is possible on the program level by other people, but not on the idea level, since as yet there are no known methods of effective selection and tying together of ideas and fundamental tenets outside of the mind that created them, but eventually, as self-understanding improves, such a method perhaps will be found.

As we have already mentioned, any problem has a goal, conditions and limitations. The goal is broken down into interrelated subgoals, which should be ordered in time and space. The limitations may be closed—rigidly assigned, their violation is prohibited (time or attainment of goal, territory, sometimes the composition of forces and equipment)—or open, the boundaries of which are either unknown or are not completely defined (for example, limitation on manpower composition in expectation of reinforcement is open). The same is true of the conditions: the conditions may be single valued, but they may also be incompletely defined. The problem may be additionally defined on the basis of experience. In day-to-day life we proceed as follows: if there are no data we try to conjecture or guess them. Experience should be concentrated in the program and accumulated as training proceeds. Experience should also determine how much detailing is desirable.

Any formal program should operate with a priori assigned categories and relations between them. The alphabet of the categories should be finite. Meanwhile real life does not fit into any alphabet. The description of a problem requires an information decision be made, which is a part of the program.
Continuous coordination of the process by which an hypothesis is derived is essential. The process branches out as a result of detailing. Subprocesses, subgoals and partial solutions appear. All this must be kept in mutual correspondence. Coordination is achieved by means of central control of the program and feedback. The question of the degree of relationship between subprograms determines the productivity of the program. A strong feedback involves preconceived hypotheses and a weak one involves disagreement. The optimal relationship can be achieved by teaching the program, i.e., by solving a series of problems, evaluating the results and making corrections.

The program should take into account the input of additional information during development of the hypothesis. Human thinking can, with astonishing ease, receive new data and include them in the thought process. An analogous flexibility is required in an heuristic program. It should be borne in mind that: a) additional information may be received at any time and it must be used immediately without destroying what has already been achieved, otherwise we would never finish; b) a request for additional information should not entail the stopping of the program and waiting, since the information may not arrive.

An example of the structure of a subprogram for simplifying the description of a problem is shown in Figure 44. A large program with two forms of ties, strong and weak, may be assembled from such subprograms. A diagram of a weak tie is shown in Figure 45.

An important part of an heuristic program is the subprogram of association formation. There is reason to assume that subprograms of this type may be the key to effective computer heuristics, at least in terms of the development of hypotheses.

The initial data for developing and commencing training in the program may consist of the opinions of the specialists relative to the directions of the initial search. To the question "From what are you beginning to construct propositions for the choice of method of combat actions, and in what area are you looking for the initial idea?" experienced commanders gave the following answers:

1) "From recalling similar situations"—10% ;
2) "From searching for the weak spot of the enemy"—35% ;
3) "From searching for the strongest aspect of our forces"—25% ;
4) "From the desired results"—15% ;
5) Other ways (basically free flow of ideas)—15% .

The first three answers may be used in a program of associations; it is more difficult to imagine the implementation of answer 4, and it is still impossible to use 5. The program of formation of associations should include categories that are tolerant to input information; a chain of
associations is formed from them. A diagram of a program of the formation of associations is illustrated in Figure 46.

The schemes discussed above contain elements of random search, without which it is impossible to generate new ideas.

The diagram of a subprogram of a specific case, i.e., of data obtained during analysis of a specific situation, is illustrated in Figure 47. These data should be used for factorization and for the advancement of hypotheses, and later on for instruction.

In situation recognition, forecasting is done on the basis of both experience and a proposed hypothesis. We will assume that several hypotheses have been developed, to each of which corresponds a result of recognition and a variant of the solution. A diagram of a subprogram for prediction and comparison is illustrated in Figure 48. The general diagram of a subprogram for developing hypotheses is shown in Figure 49.

We have examined five functional subprograms of an heuristic program. The volume of a complete program and the number of subprograms may vary, depending on the complexity of the problem, amount of time permitted for solution and the capacity of the computer. A diagram of one heuristic program is illustrated in Figure 50.
Inp ut

Supplemental information

Communication channel with limited transmission capacity

Memory

Formation of associations

Long-term experience

Mixed information

Transformation of information

Output information

Input information

Initial simplification of description

Search system

Long-term experience

Initial input to categories

Memory

Check

Output

Figure 45. Diagram of a weak tie and its informational model.

Figure 46. Formation of associations.
In order to develop an heuristic program that is suitable for solving practical problems, it is necessary to construct, adopt and perfect such programs. An hypothesis can be developed only on the basis of information. In order to work out the best method of obtaining information and for developing the optimum reconnaissance plan, one may use the results of the mathematical theory of experimental planning. The basic tenets of such a plan are: a) suitability for attainment of goal; b) feasibility; c) accuracy; d) economy (from the standpoint of cost). The plan of an experiment includes the principle and rules of formulation, methods of processing data, and methods of evaluating data. The experiment should not only satisfy the person who is conducting it, but should also be con-
Inpu t inf ormation

Long-term experience

Specific experience

Summa tion of Advancement of
information propositions

Ordering (organization) of information

Functional transformations

Hypothesis

Output

Figure 49. Subprogram for developing hypotheses.

vicing to the chiefs and colleagues. The plan should be optimal, i.e., it should ensure maximum completeness and reliability of the information about a situation at a given (or permissible) cost in terms of manpower and equipment. It should also take into consideration the tolerable risk.

Experimental planning is required for more than just the solution of information problems. The development of new methods of deployment of weapons, organization of combat training of troops and of the training process, military-scientific and military-design activity, substantiation of the organizational structure of institutions, all require experiments and the planning of experiments.

One method of developing hypotheses is to develop ideas (for purposes of obtaining hypotheses) expressed by other people. These include:

1. Brainstorm—collection of the largest possible number of ideas on a given problem, of which several of the ideas may be useful. No idea is declared erroneous beforehand. The development and evaluation of the materials obtained are done later by other people and by different methods.

2. Group agreement—a certain number of persons should come to
agreement on some problem, and in particular, propose an hypothesis. There is an optimal group makeup ("critical mass"), which gives the most productive result.

3. Polling—asking experts either to respond to questions or confirm (dispute) some viewpoint. The questions should be formulated in such a way that the response will be numerical; it should be borne in mind that man is more willing to give a critical evaluation than to answer questions himself.

Figure 50. Diagram of heuristic program (a) and the variations of its simplification (b, c, d, e): A) long-term experience: 1—simplification of description; 2—specific experience; 3—formation of associations; 4—threshold or comparison scheme; 5—hypotheses; 6—prognosis and comparison.
3. Evaluations

After proposing an hypothesis, it is necessary to objectively evaluate its advantages and find ways of improving it.

The mathematical theory of evaluations combined certain parts of the theory of probabilities and mathematical statistics and became an independent scientific discipline. The classical problem of evaluation formally consists in the following: It is necessary to determine some operational-tactical parameter, directly or indirectly related to measured values (distance, time, amount of resources). The carrier of information about the measured values is called a signal. The required parameter is calculated by processing the signal. The measuring systems introduce errors and, therefore, noise, and consequently the parameter will be evaluated with error. Theory offers a means of evaluating and minimizing the error if the statistics of the signal and noise are known. The accuracy of evaluation is determined by the ratio of these characteristics. The better we know the properties of noise (errors), the more accurate the evaluation will be. We introduce the concept of risk and risk function. Risk is a quantitative expression of the harmful effects of errors, and the risk function expresses their dependence on the error of evaluation. It should be clearly understood that certain values can be measured and other values, functionally related to the measured ones, can be evaluated.

There are various evaluation criteria. The Bayes' criterion consists in the introduction of a cost of errors (depending on the error and on the true value of determined parameter) and calculation of the mean risk, i.e., the mean cost of errors. The problem of evaluation consists in minimizing the mean risk. The Bayes' estimate, found for the least favorable distribution of the desired value, is called the minimax estimate. A value of interest to us may be both random and non-random, that is deterministic (for example, the number of missiles that strike the target, in view of scattering and failures of onboard equipment, is a random value, but the number of missiles launched is not random). It is often difficult to determine the cost of various errors, and it is assigned arbitrarily. Therefore, other characteristics of evaluations are used. In particular, evaluation may be done in terms of the maximum a priori probability or maximum likelihood. The former requires preliminary (a priori) knowledge of the law of distribution of the desired value, but this is not required for the latter. These evaluations coincide with the maximum post-experimental (a posteriori) law of distribution of the desired value. Evaluation in terms of the maximum likelihood depends to the least extent on the initial assumptions. The theory of evaluations is used for processing reconnaissance data, data on the results of military actions, demographic data, etc.

The theory of statistical solutions enables us on the basis of a mathematically formulated case to justify the choice of assumption in the
presence of several alternatives (possibilities). In order to analyze the
essence of the problem we will examine the following two-alternative
problem. Let two hypotheses, I and II, be stated. We are required to
select the one that best describes reality. If the problem is a probability
one, then we may speak of "guessing" the truth in repeated situations
in the highest number of cases. The benefit (cost) of further actions
will depend on the correctness of the choice. There are four possible
cases here:

1. Hypothesis I is approved and hypothesis II is valid at the same
time.

2. Hypothesis I is approved and corresponds to the truth.

3. Hypothesis II is approved and hypothesis I is valid at the same
time.

4. Hypothesis II is approved and this corresponds to the truth.

If the costs and *a priori* probabilities of each hypothesis are known (on
the basis of previous experience), then Bayes’ evaluation is applicable. It
offers the *minimum mean risk*. In the absence of *a priori* data we may
use the minimax criterion. If there are no data either on costs or on
probabilities, we use the criterion which at the given level of errors
*minimizes the error relative to the other hypothesis* (the Newmann-
Pierson criterion). This criterion is most applicable when the discussion
concerns a rarely encountered hypothesis. We will assume that in order
to break the enemy’s offensive operation a missile-artillery counterstrike
is prepared, which should be launched immediately before the enemy’s
artillery bombardment, no earlier and no later than some short time
interval. Hypothesis I will consider the concentration of the enemy and
his readiness for attack (counterstrike is advantageous), and Hypothesis
II will consider the opposite situation: There are no *a priori* data about
the probability of an offensive beginning at a specific point in time, and
the exact cost of operational miscalculation is not known either. The
essence of the Newmann-Pierson criterion is to establish the probability
of "false alarm," the probability that Hypothesis II is valid while Hypoth-
esis I is approved, and to minimize the error in the approval of hypothe-
sis I in cases when it corresponds to reality. The analogous case (about
the beginning of the Battle of Kursk) is described in memoirs pertaining
to the Great Patriotic War. In evaluating the situation the commanders
used (perhaps intuitively) the Newmann-Pierson criterion.

The theory of statistical solutions makes it possible to consciously
consider the maximum data about a real situation.

Suppose we have several hypotheses relative to the conduct of the
enemy and several hypotheses relative to our own conduct. The actions
that are advisable in one case may be absolutely disastrous in another.
One of the methods used for quantitative evaluation of the results of
behavior in an incompletely defined situation is game theory.¹ In game

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theory the capabilities of the sides and the goal which they pursue are limited beforehand. Each side is called a player, and each possible means of behavior is called a strategy. Nature may also be a player. Implementation of strategy is a move. It is assumed that the number of strategies of each player is finite and the consequences of using the strategies may be evaluated quantitatively by means of gain. A negative gain is a loss. The purpose of a game (battle) is to achieve maximum gain or, since a gain by one side is a loss by the other, minimum loss. Gain is a quantitative measure of advantage and benefit acquired as a result of the implementation of certain strategies in a specific situation. There are games with complete information (the player knows all previous moves each time he takes own move) and games with incomplete information, when there are no such data. A game may be represented in the form of a table (matrix); if there are two players, the table is two-dimensional. A matrix of a game in which the players each have four strategies (generally speaking the number of strategies may be different) is shown in Table 12.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>5</td>
<td>-7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-10</td>
<td>2</td>
<td>1</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-2</td>
<td>-9</td>
<td>5</td>
<td>-4</td>
<td></td>
</tr>
</tbody>
</table>

Using strategy A₁, player A can gain 10 points (the largest gain) if the enemy uses strategy B₁, but in the case of strategy B₃ he loses 7 points; in the other cases, he gains 5. Using strategy A₂, player A can gain 2 points at best, but then he is always ensured a gain of 1.

The temptation to use strategy A₁ is great; the entire question is how great the risk is that player B will use strategy B₁. This is not safe for him, since in the case when player A uses strategy A₄ player B loses 5 points. On the other hand, a combination of strategies A₄ and B₂ gives player B a gain of 9 points, so that the use of strategy A₄ is dangerous for A. If neither player has any information about the actions of the other, then it is better for player A to select strategy A₂; in any case he stands to gain. Player B has no such possibility. In our case it is clear that player A should stick to strategy A₁. This is an “honest” game (in
the sense that player A takes no risk and does not depend on his oppo-

ten taking risks using "common sense"). The position of player B in

this game is very unfavorable. First, he knows beforehand that he should

lose. Second, he has no strategy in which he would not risk the loss

of 5 or more points. In the given case, the players operate under unequal

conditions (a game with a non-zero sum); player B must carefully weigh

his moves in order to minimize losses. The method of game theory makes

it possible to calculate how often the players must use each of the strate-
gies in order to achieve maximum gain (the optimum distribution of the

probability of the strategies) and how big the gain is. Using the mathe-
matical method of game theory it is possible to depend on a result that

is stable in the statistical sense. The purpose of the described theory

is to substantiate rational behavior in a situation where the unknown

factor is the strategy chosen by an intelligent opponent, whose interests

are contrary to our own. The theory is applicable to the same degree in

analyzing situations in which the "enemy" is nature, the environment.

These are statistical games in which random properties with given prob-

ability distributions are ascribed to the second player.

One must distinguish between strict and unstrict rivalries in conflicting

situations. The combatting sides are strict rivals and their interests are
directly opposite. Allies whose interests coincide to some extent and differ
to some extent may also be rivals in the unstrict sense. In unstrict rival-
ries, the players generally pursue different goals.

We discussed above a finite number of strategies of each side. This is

essentially not mandatory. It is important that the set of strategies actu-

ally embrace all possibilities of behavior (space of strategies should be

color) A change from one strategy to another may be viewed not as abrupt, but as smooth, and the strategy itself may be considered a

function of several variables which may be continuous (distance), dis-

crete (number of launch installations) and may not even have a quanti-
tative expression (the time of day: day or night). When different values

are selected for the variables different strategies will be obtained. Determin-
ation of the space of strategies, dependence of advantage on strategies,

method of computing the gain, evaluation of the adequacy of the

strategies for the description of the possible behavior of each side, all

of these extend beyond the scope of game theory. These are problems

of situation description and development of hypotheses. Game theory

answers the question of what strategy (or set of strategies) should be

used from among those that are given. The basic mathematical concept

of games of this type is minimax: each player may not permit a greater

loss than the "minimum value of the maximum values which the enemy

may ensure himself with his best strategies." Since this situation is

mutual, the optimality of the actions of the players is free of any psy-

chological aura. But in the case when one of the partners is inclined to

take risks, the psychological aspect enters in. The number of partici-
pants in a game may be greater than two, and in this case they may act in the interests of the group, attempting to maximize the winnings of the group. Such games are called 
coalitional. Games in which the strategies are functions, for example fire distribution density or distribution of forces at the front of an offensive, are very interesting.

In the examined cases each player selects his strategy instantaneously, as a single whole, even if it is a function. But there is also a situation in which a set of moves is made until the time of “payment of gains” arrives. These are positional games (chess), in which only the final positions may be compared. Decisions may be made not at discrete moments of time, but continuously; such games are called differential games (pursuit). Games in which the choice of strategies considers the behavior of the partners are called 
dynamic; these games make it possible to describe and evaluate various military situations.

In games with incomplete information, there are always two factors: chance and cunning. Cunning is manifested in various forms: concealment of knowledge of the game from the enemy, deception relative to intentions, guessing the enemy's intentions. Here we are forced to abandon the strict confines of mathematics in favor of the wide expanses of heuristics.

The theory of reflexive games\(^1\) is helpful in describing a conflict which considers each side's idea about the opponent's train of thought. Since a model of the enemy is usually based on external observation of the opponent's behavior, the transmission of false basic data for decision making is possible. This process is called reflexive control Any disinformation is reflexive control. Concealment, provocation, formulation of the opponents' doctrine, a diversionary strike, and conveyance to the enemy of a false impression about the level of our knowledge concerning him and of our notions relative to his ideas about our concept of him, etc., are all varities of reflexive controls of different degrees. The mathematical tool as it stands today makes it possible to describe the different degrees of reflection and interaction, but it does not evaluate the true degree of reflection (on the basis of objective information). Nevertheless the theory of reflexive games is useful for analysis of situations and processing of data for evaluations, and it offers a wealth of material.

Let us discuss the method of evaluating actions that are repeated over a long period of time, a recurrent action to external events. We call these events \textit{requirements}, and actions are \textit{the servicing of requirements}.

Very many forms of military activity involve the servicing of a flow of requirements. The actions of a group of air defense missile complexes, reflecting an enemy air raid, may be described in these terms: enemy aircraft are viewed as a random flow of targets; depending on the speed

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\(^1\) The essence and levels of reflection were discussed in Chapter 5.
of an aircraft and the distance between them along the front and in depth, the concept of target flux density (the number of targets per unit of time) is introduced. Each target presents the missile complex with service requirements: to service a target means to destroy. We will assume that the group may launch 10 antiaircraft missiles in each 10 second interval, but it may turn out that there are 100 aircraft in the area under fire in some interval of time, but none in some other interval of time. How many targets in a given raid can be destroyed by the air defense group? What is the mathematical expectation of the number of targets destroyed for given statistical characteristics of a raid? There are also other questions: at what distances can targets be destroyed, how many targets penetrate into the zone of defense, what is the “down time” of missile complexes, etc. It is easy to see that the answers are important for both the attacking and the defending sides.

Similar questions arise in the preparation of a missile attack on enemy targets and defense against a missile attack, and in the organization of an air battle, naval battle, tank and antitank battle, and combined offense or defense. Such problems are solved by the theory of queuing. The basic feature of queuing problems is randomness, both of servicing requirements and of servicing time. Certain statistical characteristics of the flow of requirements and servicing system are assumed to be known. Queuing theory makes it possible to forecast the condition of a system designed for the solution of problems that occur randomly in time. Queuing processes possess general properties which are most easily explained diagrammatically in Figure 51. At some point (service center) requirements (requests) are received for any type of service. The service center may be located at one or several places; it is assumed to have several servicing

![Diagram](image-url)

Figure 51. Queuing diagram.

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channels (lines, stations). As the queue forms, it is necessary to wait until a service channel is open. The discipline of servicing may not have a priority when all requests are considered to be of equal importance, or may have priority when certain requests are serviced out of turn.

The intervals between service requests and servicing times may be: equal, unequal but assigned, and random. Servicing systems in which queues do not back up, but remain stable (within prescribed limits) or disappear, are interesting in the practical sense. The statistical characteristics are taken from experience or theory. For example, when a decision is made to develop a hospital network in the vicinity of an army operation, it is impossible to accurately determine the rate of arrival of casualties, and therefore queues may form for a time. It is vital that these queues not overload the casualty-clearing facilities, and that they be eliminated within the time period that does not endanger the life of the patients. In complex systems, queue length may have an influence on the number of channels, time and discipline of servicing.

The following characteristics of a service system are usually examined:

- average number of requests in the queue (number of requests per unit of time, averaged in some long interval);
- average time of waiting for a service request;
- probability of waiting for some prescribed time;
- probability of absence of waiting.

If the statistics of the flow of requests, number of channels, statistics of the servicing process by one channel and the discipline of servicing are given, then these characteristics may be calculated.1 Queuing theory is closely related to other branches of mathematics and its application is not limited to the assembling of ready-made formulas. Actual military problems usually require a qualified approach. Nevertheless, when a problem is formulated in terms of theory, it is solved; the most difficult task is to correctly state the problem.

Effectiveness is the most widely used evaluation standard of a hypothesis or of the results of actions. An intuitively clear concept of effectiveness (usefulness, benefit) requires quantitative expression. We will examine two results of combat actions. The first one: two enemy regiments are routed and their weapons are destroyed; our troops advance 5 km, losing up to one battalion in dead and wounded. The second: one regiment is defeated, a second is pushed back and their weapons are captured. Our forces advance 10 km, losing two battalions. Which should be considered more successful, more effective? And further, can the degree of success (effectiveness) be expressed quantitatively as one number which has a certain operational-tactical meaning? A similar problem arises in the comparison of the usefulness of like organizations or

For effectiveness it is first of all necessary to find the appropriate unit of measurement and to express it in these units. If this can be done, then possibilities are created for comparing and evaluating different categories. Such categories as damage inflicted upon the enemy, damage prevented, probability of achieving the objective, time of achieving objective, etc., may figure as the units of measurement. The selection of an effectiveness criterion does not enter into the formal method. The method of evaluating effectiveness is based on the hierarchical principle.

At first effectiveness is broken down into simple characteristics, and then each of them is broken down into even simpler ones and so on until those for which the calculation method is known are obtained (Figure 52). Effectiveness is considered to be the union of two opposite categories: gain, positive result of the implementation of a decision (or of any actions in general) and cost, losses, delays, expenses that are inevitable in achieving an objective. If the damage inflicted upon the enemy is considered as a gain, then losses suffered (operational decision) are a cost; the number of trained specialists is a cost for a training institute (organizational decision); the quantity of reconnaissance information is the time spent on its collection (information decision).

Effectiveness is written mathematically as some function; to evaluate effectiveness means to compute this function. The form of the effective-
ness function depends on the specific problem and on the gain and payment. If the gain and payment are expressed in like units, then the most convenient form is additive: gain minus payment (one side destroyed six enemy divisions, losing two of its own divisions, the effectiveness of the operation for a similar composition of the divisions is four units). Negative effectiveness means that the payment exceeded the gain. The additive form is unsuitable if the gain and payment are quantitatively incomparable: three missile launch sites are destroyed by four submarines, one of which is sunk. An attempt can be made to construct an additive function by reducing the worth of the launch sites and submarines to a common value, to the damage which they are capable of inflicting; this, however, cannot always be done. Therefore the multiplicative form of the effectiveness function is employed: gain divided by payment. The third form is the gain for limited cost. For example: destruction of the maximum number of reference enemy targets by 100 tactical missiles and motorized infantry suffering not more than 20% casualties.

It is especially difficult to compare gain and payment expressed by simultaneous losses of manpower, equipment and production resources. The expression for the effectiveness function may be complex here and may not have an obvious interpretation. Ordering may be used instead of an exact numerical evaluation: the effectiveness of hypothesis A is greater than the effectiveness of hypothesis B.

The next stages of the hierarchy are the quality indices and parameters which describe the situation and the properties derived from it. There may be many such parameters, and each of them may have an influence on any quality index. The tool of effectiveness theory makes it possible not only to determine the extent of this effect, but also to evaluate the sufficiency of the indices for situation evaluation.

Shown in Figure 53 is a scheme for computing the effectiveness of operational, organizational and information decisions in application to typical problems. A feature of the effectiveness evaluation apparatus is the fact that each new large problem from this field usually requires the development of a mathematical tool. This is particularly true of evaluations of new types of weapons. Evaluation of the effectiveness of joint operations of several services of the armed forces is an especially complex problem and involves difficulties in the substantiation of a single metric, i.e., identical units for the description of different methods of military actions. These difficulties, however, are usually not overwhelming.

4. Optimization

The following problem of operations theory consists in optimization, in the transformation of an hypothesis, as a result of which it becomes preferable in some sense to any other. The concept of optimum is closely
related to the choice and formulation of the objective of a decision. The objective may be given, but it may be a component part of the hypothesis. The objective must be matched with actual capabilities. These capabilities are expressed mathematically as limitations imposed on the values that describe a situation (time, distance, amount of resources).

The problem of optimization is formulated as follows:
—there is a mathematical dependence of the effectiveness of the
hypothesis on the parameters that describe a situation and behavior;—limitations are made on the range of choice of parameters;—it is required to find the values of the parameters for which the criterion acquires the extreme (minimum or maximum) value.

There are several branches of mathematics that deal with the theory and methods of optimization: variational calculus, mathematical programming (linear, nonlinear, dynamic), stochastic approximation, principle of the maximum, and theory of adaptation. The difference between these branches consists in the form of expression of the criterion of optimality—a method of assigning limitations and methods of achieving the optimum. The latter are divided into analytical and algorithmic. Analytical methods in principle give a general solution of the problem in formal dependence of the desired optimum on the parameters. However a graphically clear solution is usually obtained as a result of a great amount of simplification (idealization) of the initial problem, and idealization almost always takes such a long time that the solution loses its practical importance, but the analytical tool is not workable for a lesser degree of idealization. The algorithmic method consists in the indication of the sequence of actions that lead to the desired optimum.

There are global and local optima. A global optimum is valid for the entire range of change of the parameters (within the prescribed limits). Local optimum is valid for a certain area.

Optimization problems are complex. In addition to mathematical difficulties there is also a fundamental problem, consisting in the under-definition of the objective. This means that there may not be one, but several optimization criteria. In an attack, for example, it is necessary to ensure the following: advance to the prescribed lines, destruction of certain enemy strong points, infliction of manpower losses on the enemy, infliction of equipment losses, protection of our forces and equipment, economical consumption of ammunition and weapons resources, safeguarding of physical manpower forces, maintenance of high morale in our forces, etc. The extreme practically never coincide with respect to all criteria. When solving scientific-technical and production problems it is usually possible to use one criterion (for a set of circumstances) as the main criterion and to impose limitations on the others; then optimization is carried out in accordance with the main criterion. In military affairs this cannot always be done. Another approach is to find an index on which all criteria depend monotonically (as the index increases the values of the criteria increase; this index is called a monotonic argument). Optimization is done in terms of this argument. The mathematical extremum does not exist in the presence of several criteria. The following plan for a solution is most typical.

1. An approximate range (limits) of the permissible values is specified for all criteria (assault positions: not closer than such and such and
not farther than such and such; capture of strong points: not fewer than such and such and not more than such and such). These data are approximate in nature and may eventually be altered. Therefore they are rather easy to assign. The compatibility of the assigned limits is checked, i.e., the following decision is implemented: one of the extreme values of some criterion is taken (in turn) and it is determined whether the other criteria lie within the stated limits. If not, the range of tolerable values of some of the criteria is expanded and for others it is narrowed.

2. The relationship between the criteria and the effect of change of each of them on the others are determined. All the criteria except two are fixed, one of these two is changed within the established range and the amount of change of the other is evaluated (in particular it is determined whether or not the other criterion extends beyond the permissible range). All combinations of the criteria are checked and a conclusion is drawn as to which criteria may vary.

3. Partial optimization is done. The best value of each criterion is determined on the condition that the other criteria related to this one have acceptable values.

4. Joint optimization. The “gates” of the tolerable values of each criterion are narrowed as far as possible (around the partial optimum). All the criteria should be compatible at the boundaries of the “gates.”

5. Within the limits of the narrow “gates” the criteria are selected near the best boundary and optimization is done for each criterion. The order of optimization is determined by two factors: the importance of a criterion from the standpoint of the stated objective and the strength of its relation to the other criteria. After optimization is done in terms of one of the criteria (the others should be within the permissible boundaries), optimization with respect to the other criteria should not detract from the quality of the previous result.

As a result of optimization, the initial hypothesis may be improved. This does not result, however, in a qualitative change, since the idea on which the hypothesis was founded is retained.

5. Modeling

The following approach to the solution, as we have seen, is used in operations theory: description of problem—statement of hypothesis—evaluation of hypothesis—optimization of hypothesis. Unfortunately it is not always possible to describe analytically each of the stages: in many cases the course of events either eludes the observer or lacks mathematical description. Then modeling comes to our aid: the re-creation (in simplified form) of events and relations in a model, allowing the model to function and observation of what happens. The true course of process development is judged on the basis of the behavior of the model. Modeling may be repeated by changing the conditions, description, criteria of
evaluation, and then observing what happens. It must be recalled that modeling operates within the limits of the initial description, to which it can add nothing. Therefore anything that extends beyond the boundaries of the initial models cannot be observed and evaluated. Modeling is now used extensively in science, military affairs and technology.

It is important to point out the broad capabilities of operational-technical modeling. A model may include not only a mathematical description of a situation, but also of people and operators, who will have an influence on the course of events by playing certain roles. In this case modeling should take place in real time. Personnel may be replaced or reoriented toward other behavioral tendencies; in this case it is possible to determine the influence of various factors.

The solution of large-scale problems requires information which is usually not available. The recovery of this information through a direct full-scale experiment is not only difficult and expensive, but in many cases altogether impossible. Modeling (more accurately direct modeling) provides for organization of the experiment with a structure that is programmed in the computer.¹ We already know that practically any organization can be subjected to structural analysis. It sometimes turns out that the structure is unknown, but then the behavior of the formation under certain (perhaps simpler) conditions is known. A direct model may be built both on the basis of structure and on the basis of data concerning behavior, i.e., output characteristics, and may include an imitator of external action, description of the function of the investigated organization and system for interpretation of the results. External action includes random factors, and therefore the model is called a probabilistic one. A model may include some of the actual elements of the modeled organization. This is essential in cases when there is no description of these elements. Depending on our level of knowledge about the modeled organization (especially its structure), the description may be written in varying degrees of detail; this determines the level of modeling. Low level modeling makes it possible to refine properties, and consequently to detail the description and proceed to modeling on a higher level. This multistep process leads to the production of all data required for decision making. The model reproduces the description with greater or lesser simplifications, depending on the stated problem and the computer base. There is usually an intelligent compromise between the accuracy and the complexity of a model.

One of the most effective methods of describing and constructing a model is block modeling. The object to be modeled is broken down into its elements (lower formations), or blocks, each of which may be described satisfactorily and modeled independently. The overall model

consists of the models of the blocks; the connections between the blocks are also modeled. If the model is too complex to be completely reproduced by the computer each block in the combined model is replaced by a simpler description of its external characteristics, which are determined by means of a full-scale experiment or by modeling. By variously combining the blocks, it is possible to build models of various proposed structures and analyze them. Each block of the combined model, in turn, permits block representation, and therefore the modeling process is hierarchical.

Criteria are an important aspect of modeling. The criteria should correspond to the objective of a proposed solution. It is rarely possible to succeed with just one criterion; a group of criteria is usually employed. This group should be complete in the sense of the objective, i.e., it should reflect all aspects of the solution.

The modeling results are compared partially and completely with known data about the object. The accuracy and completeness of modeling are evaluated on this basis, and conclusions are drawn relative to the need for and direction of detailing of the model.

Modeling is one of the methods of further definition in the solution of incompletely defined problems. First, modeling discloses the degree of incompleteness, i.e., the range of possible behavior of the object under given (incomplete) conditions. Second, it is possible with the aid of the model to determine the character of behavior of an object with those additional factors which are introduced during further, intuitive definition. Finally, using the model it is possible to "recheck" the various methods of definition and evaluate the results.
PART III. TECHNOLOGY

Chapter 11. Computer Systems

... when the waves of industrial revolution rage ... courageous heads are needed.

F. Engels

1. Introductory Comments

The development of the computer* has sharply influenced the course of technological progress and military affairs. This may seem surprising, since the computer is essentially nothing more than an instrument capable of rapidly and accurately adding numbers. But precisely this capability made possible the solution of complex problems. Modern computers operate not only with digital, but also with alphabetical and semantic information.¹

Quantitative data, formulas, pictures, semantic and tabular text may be put into the computer. Computers can produce information in the form of a final document (filled with text), pictures, diagrams and drawings. Computers are also performing operations that make their universal application possible. But decision making requires a considerably broader range of capabilities: the computer must operate in non-metric spaces of concepts and simulate topological spaces. A new trend will possibly appear in the design of computers for decision making. A precedent exists: control computers. But it may be said with complete justification that the hypothetical new trend will represent not a new branch of technology, but rather the specialized development of technology, which is now called “computer technology.”

A general diagram of computer operation is illustrated in Figure 54. The basic element of modern computers is the processor (computer), which completes the program, and various forms of memory, control systems and data input-output equipment. By computer we mean a device in which irreversible conversion of information (including concepts) takes place. Certain specialists are of the opinion that new

* Russian term for “computer” is “elektronnyaya vychislitel’naya mashina”—literally, “electronic computing machine”—abbreviated “EVM.”
¹ Digital data concerning equipment were borrowed from the open Soviet and foreign press.
information is formed in a computer. This question is argumentative, and we shall not concern ourselves with it. What is important, is that in all other elements of the computer only the relocation of information in time and space takes place; the computer transforms the content of the information. A diagram of a computer is seen in Figure 55.

Computer progress will obviously proceed in the direction of improvement of computer components, development of computer mathematics and improvement of structural efficiency. In contrast to preceding stages, however, a new quality should be expected: the development of computer systems capable of purposeful adaptations to specific tasks.

2. Computer Components

The main structural components of modern computers are integrated circuits, which are universally replacing transistors. Integrated circuits have high speed, reliability and economy. The time required for performing one elementary operation has been decreased to 0.02–0.01 µsec, and the operations frequency is now 100 MHz. There are components in which the lag time is only 0.001 µsec. The high speed of such circuits is only a few thousandths of a microsecond (a few nanoseconds), and 10 times higher speed is completely realistic. It is thought that a rate of data input into the computer of the order of 100–200 million commands/second is not the ultimate. Magnetic computer elements, operating at a frequency of only 100 kHz, are now being used in the United States for highly reliable and flexible military computer systems, but at the same time they require minimum power and have great reliability.

The reduction of the operating time of logic elements in recent years
is illustrated in Figure 56. The graph is evidence of the intensive adoption of high-speed components.

The average integrated circuits make it possible to place 50–100 rectifiers on one base plate (in one module). From 1,000 to 5,000 logic circuits are accommodated by large integrated circuits on one base plate. This brings us close to the time when all computers will be designed as one large integrated circuit where we will have a very small number of components.

The components of the first digital computers were electromagnetic relays, and the designers did not immediately decide to convert to electronic tubes. Further development of the components' base is illustrated in Table 13.

The process of any arithmetic or logic operation consists of simpler elementary operations such as shifting of a number, and transmission of a number, etc. Each elementary operation in the digital computer is accomplished, as a rule, with the aid of a special circuit; these circuits are sometimes combined. The device that performs summation is called an adder. There are parallel adders, which contain as many one-digit adders as there are digits in the numbers to be added, and serial adders, in which there is one one-digit adder, which receives the numbers in sequence, digit by digit. There are also serial-parallel adders. A one-digit adder forms from input numerals of different digits a sum of a given place and carries it over to the next place. There are coincidence-type (operating with the aid of “and,” “or,” “no” logic elements), accumu-
lator (operating on the pulse counting principle) and amplitude (combining currents or voltages) adders. The coincidence-type adders are most commonly used. Accumulator adders or calculators are important machines. A calculator can memorize, for example, the number of arriving pulses, forming a cumulative sum. There are circuits for shifting the numbers to the right or left, which for numbers represented by the position method means division or multiplication: shifting by one position means division (multiplication) by the base of the number system. One-digit subtractors, which give the difference for a given place and the signal to borrow from the next place, are used. A full subtractor is assembled from one-digit subtractors. Ever more complex procedures, including logic operations, are constructed on the basis of combinations of these circuits (and their various modifications).

Table 13.

<table>
<thead>
<tr>
<th>Generation of computer</th>
<th>Years</th>
<th>Logic elements</th>
<th>Basic structural components</th>
<th>Rate (processor, memory), operations per second</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Up to 1958</td>
<td>Vacuum tubes</td>
<td>Standard electronic components</td>
<td>$10^2$-$10^4$</td>
</tr>
<tr>
<td>2</td>
<td>1958–1965</td>
<td>Transistors</td>
<td>Rectifier circuits</td>
<td>$10^5$</td>
</tr>
<tr>
<td>3</td>
<td>1965–1969</td>
<td>Integrated circuits</td>
<td>Groups of circuits</td>
<td>$10^6$</td>
</tr>
<tr>
<td>4</td>
<td>1969–1972</td>
<td>Medium integrated circuits</td>
<td>Small functional adders (registers, summators)</td>
<td>$10^7$–$10^8$</td>
</tr>
<tr>
<td>5</td>
<td>1972–1978</td>
<td>Large integrated circuits</td>
<td>Large functional units (processors, storage, terminal systems)</td>
<td>$10^8$–$10^9$ and higher</td>
</tr>
</tbody>
</table>

There are two methods of building computers: with a tendency toward sophistication of the circuit, when a certain computing procedure is accomplished beforehand with the aid of the appropriately assembled
switching circuit elements, and with a tendency toward sophistication of the program, when the result is obtained by repeated operation of the same elements in a certain time sequence. The optimum computer structure is determined largely by the type of problems to be solved. In digital computers, analog, rather than digital devices are often used for complex but infrequently used mathematical conversions. Suppose there is a high-speed physical phenomenon that is described by the equations for which a computer is designed. Then the input data may be converted into physical parameters (conditions) of the process, and the result can be converted to digital output data. In the case when the process takes place rather rapidly and the conversion of digits to physical values and back does not require equipment that is too complex, the analog computer may be used. An example is the Fourier transformation, which is often used in problems of radio signal processing. Such transformation is accomplished holographically in fractions of a microsecond, whereas digital transformation requires hundreds or even thousands of operations (depending on accuracy).

We stand today on the threshold of the development of components with an actuation time of the order of 1/10 of a nanosecond. This gives us reason to expect a new qualitative advance in the development of computer technology.

Binary storage elements occupy the dominant position in data storage systems. The byte unit (symbol) is used for measuring storage capacity. A byte consists of one letter or typographic symbol (question mark and exclamation mark, 2 decimal numbers, special symbols). A data storage device is depicted diagrammatically in Figure 57.

```
\begin{figure}[h]
  \centering
  \includegraphics[width=0.5\textwidth]{figure57.png}
  \caption{Diagram of the storage device: 1—information accumulator; 2—input-output block; 3—address block; 4—control block.}
\end{figure}
```

There are storage units with sequential access, in which the required information is retrieved by examining the storage unit from the very beginning; with cyclic access in which the storage unit is continuously examined and retrieval is accomplished at the moment when the pickup is located in the position where the required information is stored, and with random access in which retrieval is accomplished without examination of the entire storage unit according to a specified address. Storage units may have erasable or non-erasable recordings. The former is more
economical, since it makes it possible to replace masses of information without replacing the unit. Recording can be accomplished both during manufacture of the storage unit (mathematical tables, for example) and during the operating process. Storage units with erasable recording are divided into static (in which maintenance of the state of the storage unit does not require an external power such as electrical voltage) and dynamic (in which the recorded information is stored until energy arrives from outside). Various data carriers, characterized by the volume and access time for the retrieval of information, are used for data storage.

Punch cards, i.e. cardboard cards with holes, have been used since the end of the 19th century. Punch cards and punch tape are data storage devices with non-erasable recording and sequential access. Magnetic electrical and electromagnetic storage devices are made of magnetic materials (tape, drums, discs, ferrite cores, ferrites of complex shape, thin magnetic films), trigger circuits, large scale integrated circuits, etc.

For permanent storage information files, to which particularly fast access is not required, magnetic tape (high-quality tape-recorder tape) is used. Up to 3 billion bytes (1.5 million pages) may be stored on magnetic tapes. A library can be made up of magnetic tapes. Tape length is 6 million bytes, i.e. 500 meters. The recorder index of the readout speed from the tape is 300,000 bytes/second (a book may be read in only 20 seconds); the readout speed is usually lower. It is possible to read several tapes simultaneously. Magnetic tapes are sequential access, erasable static storage devices. The chief disadvantage of tape is the difficulty of access: the tape must be advanced in order to reach the required place.

Magnetic drums are rapidly rotating cylinders, coated with magnetic film. Recording and readout are accomplished with the aid of electromagnetic heads, designed similar to magnetic recorder heads. The magnetic drum is a static, cyclic access storage device with erasable recording.

Magnetic discs are among the most modern data storage devices for permanent memory. The storage unit consists of 30 to 50 metal discs coated with a magnetic film, and a magnetic head which can be moved to any disc. The entire system resembles a 50-record juke box. Transfer of the head from place to place takes not more than 0.1 second. More than 20 million bytes of information can be stored on one disc. Readout proceeds at the rate of up to 1 million bytes/second, which makes it possible to read 500 pages of text/second. Magnetic discs are random access devices, which is their chief advantage.

Operational memory devices with rapid access are often designed on magnetic cores. The fastest core storage devices had a cycle (recording and retrieval) time of $0.5 \times 10^{-6}$ sec, although models were designed with 5 times less access time, and devices with 10 times less cycle time are
expected. A core is a small ring. The storage capacity of one unit is 1 million bytes, and retrieval time is 0.35 µsec.

Flat thin-film elements have higher speed and less access time than ferrite cores. They have been used in very high speed scratch-pad memory units. Specialists consider that storage devices can now be designed on flat magnetic films with a capacity of 80,000 bytes and a cycle time of 0.2 µsec, and cycle time is expected to be reduced to 0.1 to 0.05 µsec. An ordinary 100 page scratch-pad measuring 14×20 cm, made of the same film, can be read in 0.1 second, and it is equal in terms of the amount of information stored to a printed volume. Data storage devices built on integrated circuits (crystals) can reduce retrieval time to 0.02 µsec and less. Scratch-pad memory units for table model computers have a capacity of 13 bytes per 0.05 mm² and a retrieval time of 0.4 µsec. More than 10 million bytes can be stored in one cubic meter of a data storage system built on integrated circuits. The data can be read in one minute and any information can be retrieved practically instantaneously. Modern technology is capable of producing such systems.

Cryogenic memory cells operate at very low temperatures (from a few degrees to tens of degrees on the Kelvin scale). Cryogenic storage systems have a retrieval time of the order of a few microseconds; specialists consider the development of a storage system with a capacity of 20 million bytes to be feasible.

In holographic optical memory systems, the data bank is photographic film, and recording and readouts are accomplished with the aid of a laser beam. Holographic plates measuring about 60 cm² can store up to 20 million bytes of information. When this capability is achieved a library of 300 volumes can be recorded on 10 plates and read in ½ hour. Crystals can store 1000 times more information than ordinary holographic materials. Data storage systems based on special films have greater capacity capabilities. There are also storage systems based on electrostatic memory tubes.

Of special importance in computers designed for decision making is retrieval memory (associative memory). An address is fed to the input of the ordinary memory and data recorded at that address are taken from the output; data are fed to the input of associative memory and the address of these data which agree with the initial data, is taken from the output. If agreement is achieved, then related information is located according to the address. Associative memory facilitates to the greatest extent operations with semantic information. Associative storage systems may be designed on the same storage devices as operational storage systems.

Some specialists are of the opinion that solid state memory will find ever greater application in fifth generation computers. Memory on metal oxide semiconductors will be basic.

The capabilities of data storage technology are great, and if they lag
far behind the human brain in terms of capacity, they substantially exceed the brain in terms of retrieval speed. Address and control units should contain elements capable of processing electrical impulses, which directly record or select information.

Presented below are some comparative characteristics of computer and human memory, published in the literature (Table 14).

### 3. Computer Mathematics

The foundation on which operations in the computer are based is the number system. There are positional and non-positional number systems. In positional systems each digit corresponds to some number and a certain weight is ascribed to each digit. Any number written in a positional system is equal to the sum of numbers corresponding to its digits and taken with weights which correspond, in turn, to the places in which these numbers stand. In the decimal counting system, for example, 10 initial non-negative natural numbers (including zero) are placed in correspondence with 10 digits, and the weights in the integral part of the number are 1, 10, 100 and so on, and in the fractional part, 1/10, 1/100, etc.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Computer memory (operational)</th>
<th>Human memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum storage capacities, in bits</td>
<td>$10^7$–$10^8$</td>
<td>$10^{10}$–$10^{15}$, to possible $10^{21}$</td>
</tr>
<tr>
<td>Storage density, in bit/cm$^3$</td>
<td>$10^4$</td>
<td>Brain—$10^{12}$, embryonic cell—$10^{23}$</td>
</tr>
<tr>
<td>Number of operations per error</td>
<td>Transistor—$10^{15}$, tube—$10^{12}$, computer—$10^{10}$</td>
<td>Neuron—$10^{3}$, brain—$10^{12}$</td>
</tr>
<tr>
<td>Storage capacity, in sec/bit</td>
<td>$10^{-15}$</td>
<td>$10^{-15}$</td>
</tr>
<tr>
<td>Power consumptions in Watts system with $10^{15}$ bits</td>
<td>Transistorized computers—$10^{12}$</td>
<td>$10^{1}$</td>
</tr>
</tbody>
</table>
The positional number system most commonly used for computers is the binary system (each higher position corresponds to two units of the previous position). This is convenient, since instruments with two stable states are simplest and most compact. Positional number systems have an important disadvantage, namely interposition connections, which influence the methods of performing operations and in the final analysis limit speed.

Non-positional number systems include the system of residual classes. In this system, numbers are shown as a residual (remainders) from division by the selected bases. A positive integer is represented as a set of remainders in such a way that the number in each position is the smallest possible positive remainder from division by one of the bases. The advantages of this system are independent formation of the digits of a number, small remainders, possibility of parallel processing; the disadvantages are lack of visual comparison of numbers (the external recording of a number does not give a representation of its magnitude), limited operation of the system with positive integers, lack of direct approximate performance of operations and rounding off. Nevertheless these difficulties can be overcome or avoided, and non-positional systems compete successfully in the computer with positional ones.

Symbolic systems, in which numbers are symbols, are also possible. Some group of symbols is placed in correspondence with each number. Here the concept of position is meaningless. Operations in the symbolic system should be mathematically proven in the corresponding manner.

Regardless of the method of representation of numbers, all mathematical transformations serve one purpose: to reduce a problem to the form in which all known and established arithmetic rules can be used. Whatever the problem might be, in the last stages of the solution, arithmetic is used in order to get the answer in the form of a number. In classical arithmetic four rules of operations on numbers are used, with the aid of which all problems are solved. The initial operation is addition; repeated addition is called multiplication, and subtraction and division are the opposite operations. Three more operations are used in algebra: raising to a power, extraction of roots and taking of logarithms.

Arithmetic operations are proven in the space of real numbers. Since the solution of a practical problem must have a numerical expression, all problems are mapped into the space of real numbers. But this does not mean that the solution process, all intermediate operations, should be mapped in this space. It may be considerably more economical to use another approach, in which the solution process takes place in the functional space of the problem, and only in the final stage is this space converted to the space of real numbers.

Computers also use arithmetic, called computer arithmetic. Even for the computer, addition is a universal operation, since if the computer is
designed on elements that know how to add, then it can do everything else. Algebraic operations can also be reduced to repetitive arithmetic operations; the same may be said of differentiation, integration, solution of differential equations, conversion of matrices, etc.

Another trend developed during the evolution of the computer. Multiplication and division are common in everyday life, and this is why it can perform these operations without resorting to addition. This is more convenient and faster for many problems. Likewise, the extraction of roots and taking of logarithms became routine operations after the appearance of mathematical tables and the slide rule. The same fate befell the trigonometric and special mathematical functions: as the corresponding tables were introduced into practice, these functions became the symbols of a primary, typical operation, which differs from simple addition only to the extent that addition is done in the mind while the value of the Bessel function for some value of an independent variable is found in a table. Tables may be stored in computer memory and referred to as needed. But this approach to improving the efficiency of the computer is not promising: the tabular memory must be too large, and access to such a memory takes too much time.

Complex operations on numbers may be performed not consecutively, but in parallel simultaneously. If a component is constructed which "knows" how to take cube roots just as fast as the adder adds numbers, then, for problems in which extraction of the cube root is the prevailing operation, such a component will be indispensable.

Let us assume that we need a computer for solving high-order linear algebraic equation systems. We know that the typical operation in such problems is matrix conversion. This is a complex operation and it requires much time. We assume that we have an instrument that converts matrices by modeling some physical process. If the instrument is simple, compact and reliable, it can be used as a typical computer component, which reduces by thousands of times the time required for solving large equation systems. The matrix conversion operation becomes an ordinary operation, which may be included conventionally among the arithmetic operations. The only difference is that the determination of the reciprocal of a number is accomplished in the space of real numbers, and determination of the inverse matrix is done in matrix space, i.e. in some functional space, which in the case at hand is identical to the space of the problem.

The computerization of complex mathematical transformations, used repeatedly in some class of problems, led to the development of specialized computers. A specialized computer operates very rapidly according to a single program.

However, a specialized computer operates in its own specialized functional space, which will coincide with the functional space of a problem in extremely rare cases. First, a specialized computer usually embraces
only a part of the problem. Second, the problems are diverse and each one may form its own functional space. It is possible to design a computer on the basis of a group of specialized computers, which in combination cover all required computations. This approach sometimes is taken (the connections between specialized computers, i.e. interface computations, are accomplished using ordinary arithmetic) in the design of computers with extremely narrow application. Such computers are extremely effective for the solution of a narrow class of standard problems, but they are either completely unsuitable or disadvantageous in the event of the smallest deviation from the standard. The chief disadvantage of computers built on specialized computers is the fact that the functional spaces of each of them are independent, diverse and in combination do not form a single functional space, within which the general laws are valid.

Single computational rules cannot be established for different sets, or topological and metric spaces. Each space is a unique mathematical world, in which unique laws are valid.

But it is sometimes possible to substantiate a rather broad class of problems, within which all problems may be described in the same functional space. The laws of this space may be used for proving specialized, functional arithmetic, which will be much more effective (for problems of its own class) than ordinary arithmetic of real numbers. The number of basic arithmetic operations depends on the properties of the space and may vary. For each operation there may be designed a corresponding computer component, which performs the operation, but if there are “primary” operations (the role of which is analogous to that of arithmetical addition of real numbers), then the components that perform these operations will be sufficient.

And so, is it possible to substantiate functional arithmetic for problem solving?

Military problems have a certain generality, which was partially disclosed when the classification of solutions was introduced. Even closer to each other are problems that may be solved by one and the same method. The data filtration method (for information decision making), for example, is accomplished in the functional space that is common to problems of a rather broad class.

The theory of functional arithmetic is developing rapidly, and there is reason to assume that its advantages will be used extensively in computers of the future. Functional arithmetic in methods of analogies, inversion, comparison and recognition, and also in problems of evaluation and comparison, is considered to be especially promising.

4. Structures

The classical computer arrangement (Figure 58a) is based on strict functional specialization of the main elements (units) and their inter-relationships. The arrangement has a deterministic stable structure. It has
changed gradually, but the principle of determinism (stability of functions and interrelationships) has remained intact. The most precise modern computers are characterized by the structure illustrated in Figure 58b. This diagram is shown in more detail in Figure 59. It includes several types of processors: general purpose processors with different productivities, capable of operating according to any program; specialized processors, adapted to certain programs, which they carry out considerably more rapidly; and standard computers, which operate according to one program, but very rapidly. The idea of the multiprocessor structure consists in the economic expenditure of computer resources and rational priority of problems applicable to the purpose of the computer system. It was discovered at one time that the various systems worked only part of the time and were idle for the remainder of the time. Then an attempt was made to distribute work in such a way that all systems would operate uniformly. This made control more difficult, but it provided the possibility of performing several operations simultaneously and thereby substantially increased productivity. Such systems became known as time-sharing systems. Since the first attempts at combining the input-output systems and the central processor, time-sharing systems have undergone rapid development.

In connection with the need to process all informational files in a
short period of time with a simultaneous increase in the number of consumers, a need arose for exchange of information among computer components at the complete program level. In order to utilize the resources of a computer to the utmost, the processor and other components must be switched during operation from one program to another in accordance with current requirements. Because of this more programs are in the process of being carried out. There are two methods of interrupting and switching programs. In the first method, (hard interruption) the processor is stopped immediately as soon as the signal is received, its state is memorized and control is transferred to a new program. In the second method (soft interruption) there is a special unit, in which the interrupted signal is stored and interruption is accomplished at suitable moments of time.

By utilizing several programs, modern computers are capable of simultaneous data processing according to several programs (multiprogrammed processing).

Since the information files being processed and the volume of the programs have become so great that it is practically impossible to store them in the operational memory (with a short data retrieval time), a bottleneck occurs: the processor could insure considerably higher data processing
speed, but it is impossible to take advantage of this capability in view of the great amount of time spent on access to the long-term memory. One possible way of solving this problem is by program (and not technical) methods to condense the information. The information usually contains considerable redundancy, and mathematical information is no exception. If redundancy is eliminated from the input data, then their storage requires considerably less memory. One means of reducing the redundancy of semantic information is to convert from free speech to the formulation of standard or non-standard statements. Here superfluous phrases, words and symbols are excluded. It is considerably more difficult to detect redundancy in programs, but more detailed analysis shows that there is redundancy even in exact mathematical relations. If there are many equations, the symbols in them may be redistributed, classified and represented in a form that requires the minimum units of information for memory. This is what is meant by compression of formula information. Compressed information cannot be used for computation, since it does not reflect the order of computational procedures. (Letters and the order in which they follow each other in a long sentence may be coded in exactly the same manner: such a code will contain fewer binary units than the letter-by-letter code of the sentence, but it cannot be read). But by taking advantage of the speed reserve, it is always possible to expand compressed information, to impart to it the initial form and use it for its intended purpose. Methods of compressing information are developed in application to specific problems.

The new trend in computer design consists in high parallelism of data processing (distributive processor, see Figure 60). The computer is assembled from identical interconnected units, each of which has a processor and a storage unit with the required volume (Figure 61). From such components, it is possible to construct general purpose and specialized computers, just as a living organism is made of cells. Each unit is essentially a small computer, and the entire system may be represented as some number of storage systems, each of which has its own small processor. The units are combined into interconnected groups; a group has a control unit. All units are physically identical, but functionally they are capable of being in different states. The extent of control that is exercised by the control unit may vary, depending on what function the given unit performs. Each group in the system may operate independently of the others, but combined operation of several groups in the solution of the same problem is also possible. Such a setup has all the advantages of multiprogrammed processing, insures complete utilization of all components and has high flexibility.

One means of optimal utilization of computer components is known as the principle of retrieval. An external control panel, which distributes the problems and systems, is added to the computer structure. The functional units continuously examine requests, seeking work which
they can perform. Computers designed on this principle feature high accessibility for consumers.

The next structural innovation is the **associative buffer**: between the operational memory and processor is placed a super operational memory system, information exchange with which takes place in entire groups (blocks) of words. In general, exchange between different forms of memory is best accomplished not in words and phrases, but in large files (pages), in which the information should be appropriately composed.

The new large computers incorporate the hierarchical memory structure, for example, the superfast scratch-pad system, superfast buffer storage system with preliminary prescanning, rapid high capacity operational storage, and permanent storage system. The basic problem of hierarchical memory, namely the problem of addressing, cannot be considered resolved, but there is reason to believe that it will be solved in the near future.

According to V. M. Glushkov the principle of one-time data input is very important for computers used in control systems. Much of the data
with which it is necessary to work should be fed in one time and never removed. Information intended for permanent use should be accumulated. Furthermore, the "pipeline principle" is proposed instead of consecutive and separate processing of different types of data—as the "cloud of bits" travels through the system, the entire flow of data is processed according to subsequent commands, overlapping in time. Computer users may have different plans relative to implementation of the results: the repeated input into the computer, teletype transmission, or display. The computer should take into account the plans of the user, so that the output system does not limit computing capabilities. For this reason the characteristics of all the components, the structure of the computer, and functional interactions are formed in such a way as to prevent bottle-necks.

High-speed computers, capable of performing 5 million algorithmic operations per second, are used extensively. An increase of speed to 50 million operations, and eventually to 500 million operations and more per second, is planned. Future computer capabilities will not be redundant; however, there is reason to believe that some deficiency will remain for a long time. The table presented on page 246 gives an idea of the growth of computer capabilities.  

In spite of the rapid development of the computer technology, output cannot always be increased by making computers larger. This is sometimes impossible because the computers of the required output are not in production, and sometimes this is not advisable for economic or tactical reasons. There is another way of increasing computer capability—by developing multicomputer complexes. If all the algorithms that comprise information processing are independent of each other, then organization of the simultaneous operation of several computers usually poses no difficulty. In the case of a series connection of the algorithms (when it is impossible to advance before finishing the computation process on the first algorithm), solution time reductions can be achieved only through paralleling of the algorithms themselves and transmission of parallel blocks to individual computers. There is a scheduling theory that gives the optimal solution for this problem. The principal of optimization consists in determining the set of possible variations of distribution of parts of algorithms among the computers of the complex, evaluation of the solution time for each of the variations, and selection of the variation for which the solution time is minimum. A computer with a deterministic structure continues to be improved as a result of an increase in the volume of the structure, optimization of the interrelations among the units, and microminiaturization of the components.

1 See also: T. Earl, 'Towards a Fifth Generation,' Science, 1970, October, Volume 6, No. 10.
We will consider another structural principle: the structure with random connections.

The above considerations were based on the fact that a solution algorithm exists. It was assumed that the algorithm may be constructed and fed into the computer. For many problems requiring decision making, the algorithm cannot be formulated ahead of time. Pattern recognition is an example. Let us assume that we are required to compare two situation maps, that the maps are in different scales, and projections and the situations are written in different languages and different (although known) symbols. The operator requires much time in order to perform such work, but the work is fundamentally not difficult. However, it is

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**Table 15.**

<table>
<thead>
<tr>
<th>Generation of computer</th>
<th>Capacity of operational memory, bits</th>
<th>File size for direct exchange (without tapes), bits</th>
<th>Set of instructions</th>
<th>Mathematical support</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$10^3$–$4 \cdot 10^3$</td>
<td>$10^7$</td>
<td>$&lt;100$</td>
<td>Computer languages, subroutines, multipurpose programs, program libraries; assemblers</td>
</tr>
<tr>
<td>2</td>
<td>$2 \cdot 10^4$</td>
<td>$10^9$</td>
<td>$\sim 100$</td>
<td>High-level languages. Monitors, microassemblers, control programs.</td>
</tr>
<tr>
<td>3</td>
<td>$5 \cdot 10^5$</td>
<td>$10^{11}$</td>
<td>$\sim 200$</td>
<td>Operational systems, language systems, multiprogramming, program packages, modeling languages, modular programs</td>
</tr>
<tr>
<td>4</td>
<td>$10^6$–$5 \cdot 10^6$</td>
<td>$10^{13}$</td>
<td>$&gt;200$</td>
<td>Expanded languages, meta-translators, systems realization of subprograms, conversational mode</td>
</tr>
<tr>
<td>5</td>
<td>$&gt;10^7$</td>
<td>$&gt;10^{15}$</td>
<td>$&gt;1000$</td>
<td>Programming by &quot;what to do&quot; principle, systems realization programs, natural languages</td>
</tr>
</tbody>
</table>
very difficult to write a computer algorithm that is suitable for practical application. Situation recognition is even more difficult. In situations we deal with dynamics and forecasting. Man can cope with such a problem, although with difficulty; but how to program his actions is a completely unanswered question. A computer training algorithm can be constructed on the basis of experience. The computer is given a training sequence. In terms of volume, it is presumably sufficient for supplying the computer with all the required information. Let us assume that we want to teach the computer how to recognize "defensive" and "offensive" situations. This problem calls for division of all possible situations in two classes. The training process will consist in presenting the computer with, let us assume, one thousand variations of an offensive situation and one thousand variations of defense. These 2,000 variations comprise the training sequence. After training, a test is written: a new situation is presented and an answer is received: "defensive, offensive, I can't recognize." In this case we limited beforehand the number of classes to two, named them and stated for each object of the training sequence the class to which it belongs. This is training. But another approach may also be taken.

The computer itself can be allowed to classify the 2,000 variations according to the indices of proximity among them. This will be self-instruction. The attractive concept of employing teaching and self-teaching algorithms has one difficulty: the concept, the principle of teaching, must be formulated. Indeed, very often we ourselves cannot distinguish the specific content of similarity criteria, let alone formulate these criteria in such a way as to put them into the computer. It is hard to explain how we recognize a person or a voice after the first word is spoken on the telephone by a person whom we have not seen for 20 years. It is difficult to formulate the criteria of recognition, but it is often difficult to precisely formulate (specifically to formulate, but not explain) the principles of classification. Classification requires comparison of indices and the relations among them.

The process of classification and recognition includes the separation of an object (situation) into elements and determination of criteria; the construction of patterns according to different communication criteria; synthesis; decision making. The characteristic properties of the process are very large input information flow (since we do not know ahead of time what information is required for training, we must put into the machine all the information that is available) and uncertainty in the specific content of each of these functions. In discussing the structure of the computer, we established that the data input systems are a bottleneck (and the flow of input information is very great), and also that speed may be increased by decreasing memory access time through the use of specialized computers (but uncertainty interferes here). Therefore, we may assume that circuit methods of designing a recognition system may be
more successful in certain cases than programming methods. Research has shown that there is some substance in this assumption. A special class of devices with a random functional structure, probably closer in some ways to the living brain than a deterministic computer, has been developed. The chief difference is that these devices do not use a formal language. Their language is a language of patterns, and the chief factor in data processing is the relationship among the elements of the pattern.

One of the representatives of this class of systems is the perceptron.\(^1\) The perceptron consists of a set of elements connected into a single system. Each of these elements, after receiving an input signal (either from the environment or from other elements) creates an output signal, which is transmitted through connections to a group of other elements. Some elements of the perceptron (input) can perceive external signals. Others are intermediate. One or several elements are output elements; they process signals that are fed into an ordinary digital computer (or the operator's indicator). A schematic diagram of the perceptron is illustrated in Figure 62. The logical properties of the perceptron are determined by the structural arrangement, threshold levels and training methods, and also by memory. Logic is developed by “reinforcing” the memory states of the perceptron, i.e. by stabilizing or strengthening the order of formation and transmission of signals, which facilitates the solution of the problem. Behavior of the perceptron is determined not by an algorithm, but by the gradually developing displacement of characteristics. The perceptron has three groups of elements: S-elements (sensor elements) are any sensitive elements capable, under external influence (for example, the arrival of a coded signal or a ray of light of a certain intensity), of producing an output signal. A set of S-elements

\[\text{Figure 62. Diagram of a perceptron.}\]

comprises the system for parallel reception of input information, which is extremely important for achieving high transmission capacity. A-elements (associative elements) are capable of producing an output signal if the number of arriving input signals exceeds some threshold; the S-elements are connected to the A-elements by various connections (random, let us assume). R-elements (reacting elements) are capable of receiving signals from A-elements and producing an output signal.

The time required for transmitting a signal from one element to another through the communication channel and the weight (significance) of the communication channel are taken into consideration in the operation of the perceptron. These parameters are controlled and depend on the memory. There is a system of reinforcement, i.e. a set of rules (established beforehand or developed during the self-instruction process), on the basis of which it is possible to change the time required for passage of the signals and the weight of the connections, and consequently the state of memory.

The operating principle of the perceptron consists in the following: Let us assume that the rules of reinforcement are such that the influence on the output system of those connections (weight of connections) through which a signal passes twice in succession is increased, and is decreased in the case of double gap. The very same object is shown 10 times in succession, and consequently, on the field of S-elements (and in the very same place) the same image is projected 10 times. The S-elements that were in the path of the light ray produced signals that excite the corresponding A-elements, and then the R-elements, and an output signal is received. Since the same elements are excited in each showing, the output signal increases from showing to showing due to the increase in weight of the corresponding connections. The weights of the other connections gradually decrease. Suppose that after 10 showings of the training sequence a new and unknown object is shown. If it coincides with the previous one, a strong output signal is received. The more it differs from the previous one, the weaker the output signal will be.

Thus a certain type of program may be written, for example an object recognition program. The structural diagram of the perceptron is close to a functional diagram of a recognition system. The establishment of connections and the formation of patterns in accordance with various criteria take place in the A-element unit as a result of the random construction of the network of connections and reinforcing system. The examined system is known as a three layer perceptron (layers S, A and R). Of course, such a system has a long way to go before it can recognize complex patterns, not to mention situations. It is important, however, that a new and promising principle is being developed.

The multilayer perceptron, which has more layers and connections, is more promising. An effective reinforcement system can be established in the multilayer perceptron due to the presence of several A-layers. By
virtue of parallel connections, it is possible to form on each layer a pattern in application to a certain criterion of connection, and subsequent synthesis can also be accomplished in the A-layers in various combinations (taking an example using a map, patterns may be constructed on three layers by arrangement, by symbols and by content, then they may be synthesized two by two, after which final synthesis and decision making are accomplished).

The capabilities of the perceptron depend to a great extent on the number of elements that can be placed in each layer, and also on the "density" of the connection network. Successes in the development of integrated circuitry indicate that success can be expected in this problem. If $10^{10} - 10^{11}$ elements can be placed in the S-layer and $10^6$ elements in the A-layers, then the perceptron will have enormous capabilities. In the classical form, the perceptron is capable of perceiving static information; it is impossible to impart the dynamism of the situation to the perceptron. If the properties of a process are known and can be assigned by a few parameters, comparison and recognition can be accomplished algorithmically according to these parameters. If the properties of the process are unknown, teaching or self-teaching will be required. The purpose of teaching is to acquire the capability of predicting the development and result of a process. The concept of the perceptron was used in the design of a predicting device.¹

The apparatus has deterministic sensors, tuned to receive certain descriptors that characterize a process, group of associating elements, positive feedback circuit and output sensors. The diagram of the apparatus (its designation is "Alpha") is illustrated in Figure 63. If the descriptors that characterize the movement of troops to a point of concentration (the number of people and equipment passing through certain points; the time of formation and resolution of bottlenecks; transmission capacity of supply points, etc.) are transmitted to the input of the system, it will study these descriptors, find their laws of change, form paired, triple and other combinations, study the laws of change of the combinations and in final analysis work out a prediction function that can be used for determining the number of troops that can be concentrated within a prescribed time. The construction of a prediction algorithm is very difficult, since the factors that influence the process of concentration are numerous, and it is not always known how they interact with each other.

The problem may be stated differently. By self-teaching [machine learning], the computer (system) found the defining descriptors and acquired the capability of predicting the course of a process. If another process is fed into the machine, it will be able to study it and evaluate the similarity between the processes, in particular to determine whether or not it is one and the same process. Recognition processes may be

formulated on the basis of this principle. There are different versions of process prediction and recognition systems, but their operating principle is similar to some extent to the one examined above.

Although the actual capabilities of recognition systems are still limited, the promises of their development are very great and their range of application will probably exceed the most optimistic forecasts within the next 10 years.

One of the possible trends in the development of teaching systems is illustrated in Figure 64. It is possible to project a map and plot the situation and plan of combat actions onto a S-network of receptors. The A-elements are grouped in such a way that each group has its own reinforcing system. Each group of A-nets transmits information to its own group of R-nets, which is connected to a general purpose computer. Several patterns that consider the different aspects of the situation are formed in accordance with each of the reinforcing systems. The first A-group, for example, may have a reinforcing system that stresses the ratio of forces in each sector of combat operations; this reinforcing system should consider the initial state of the troops, their rate of movement and the number of weapons. The specific weights of the individual sectors of the conflict may be reinforced in the second A-group from the standpoint of general operational conceptions. "Reinforced" in the third A-group is the damage that may be inflicted upon the enemy by tactical missiles and air strikes; our own losses are considered in the fourth group, and so on. Signals appear at the output of the R-groups, which correspond to each specialized pattern. These signals are processed with the aid of an effectiveness evaluation program and weak points are disclosed. We will assume that to the input of such a system is fed a series
of variations of similar battles with a known outcome (historical examples, a description of previous battles, or a number of military exercises). Machine learning takes place in the course this series, as a result of which the system acquires the ability to recognize the variations, to evaluate them and determine the weak points. The next step is to include in the computer program a correcting subprogram which will alter the new (not included in the learning series) version and the desired direction by strengthening those factors that increase effectiveness and weakening those factors that decrease the effectiveness. Feedback may be used, by means of which the results of the operation of the correcting program are transmitted directly to the S-net through a beam pen. As a result, the new, improved version of the solution will be worked out automatically. If the initial version of the solution is given by the operator, then the examined system may be considered a thought amplifier. One of the versions of the learning sequence or some general version may be used as the initial system. It will obviously be poor at first, but the system can improve it.

The concept of random connections between the elements and random reinforcements, organized during the learning process, was fruitful. During the process of improvement of learning systems, the components of the structure will apparently become more sophisticated to a level where each of them will themselves be a miniature computer. Then new capabilities will be made available, about which we can only guess. Deterministic and random structures are in a certain sense alternatives. Which structure is more effective and more promising for computers used for decision making? The answer to this question is not easy to find. Deterministic computers have been used for a long time, are widely adopted, and
have a potent and rapidly developing component base. The paths of their development are more or less clear. The computers of random structure are not yet competitive, and are still in the development stage. About the only representative of such devices is the perceptron (with narrowly specialized application, namely pattern recognition). They have an inadequate and perhaps unsuccessful ("foreign") component base, and in addition, they are not "popular." The trend toward structural similarity (distributed processor in deterministic computers and programmed output of the perceptron) is obscure and may not have appreciable consequences. Nevertheless, the potential capabilities of random structure compel us to stop and think. It can be said that in view of the great variety of problems involved in decision making, no computer with a rigid structure can satisfy all requirements. What is needed is a computer design which would permit transformation of the computer by modeling the structure of a specific problem. The computer should be arranged in such a way that it need not be told how to solve a problem, but simply what is desired to be done, i.e. state the problem. As far as the statement of the problem goes, the computer itself should construct its own scheme similar to the operations of the perception. However, machine learning of the perceptron requires a series of similar problems (learning series); such problems are usually not available, not to mention the time required for learning. Determination of structure should be accomplished on a higher level of generality, which overlaps to some extent the initial uncertainty. In this sense, the computer should operate in the same manner as man.

And so, there is a requirement to combine in one system the capability for reorganization and self-organization of random structures (of which deterministic structures have comparatively little) and the capability to use accumulated experience on a different level of generality, i.e. programmed purposefulness of the deterministic structures (which random structures, and they remain random structures until learning, do not possess). Then we may expect a new quality—purposeful self-organization.

A version (not the only possible one, of course, and still disputable) of a structural unit that may possess the required properties is illustrated in Figure 65. The structure is built of many units in accordance with the same principle as each individual unit. The purpose of the address system is to distribute the input data among the components of the primary processing system and to distribute the output information. The primary processor samples the input data, selecting the data to be subjected to further processing. The components of the primary processor comprise the unique receptor field, i.e. a parallel structure with a very large number of receiving, recording and processing components. The connections between the components and the weights of the connections are assigned by the control system. The selected information is sent on to the secondary processor, which operates according to a program. The result is read out through the address system and it is used simultaneously for
learning. The choice of program is a control factor; at the same time random sampling is possible (among some group of programs). A control system assigns the structure of the primary processing system, the program (or range of random program selection) of the secondary processing system, the method and level of reinforcements ("penalties" and "incentives"), and the method of addressing input and output information. The control connections are feedback circuits, the weights of which may also be changed during learning and interaction with other analogous units of the computer system.

The thesaurus stores a priori information on various levels of generality, all programs and all intermediate and final results used in the learning process. The random factors within the unit are the weights of the components, connections and programs. Ordering of random factors during learning or self-teaching introduces the most effective degree of determinism into the structure of the unit.

Figure 66 shows a sample structure of a second level computer assembled from typical components. It also contains primary and secondary processing, control and thesaurus units, but each of these units is constructed by a more complex structural scheme. This structure essentially resembles the initial one, but it permits wider specialization, which is used for making the structure of the computer more compatible with the structure of the problem. In particular, the address system has an internal thesaurus and control, which determine the method of distribution and redistribution of information (depending on the intermediate results) among the components. The primary and secondary processors can have several levels each; the weights of the connections between levels are determined both by internal and external control. The thesaurus has its
own processors, which distribute information among different forms of memory (the memory elements may be the same as in the receptor field and other systems). Third and higher orders of computers can be designed in like fashion. The order of complexity of the computer, the volumes of the structures of each system are determined by the class and size (scale) of problems to be solved. It is not hard to see that by simplification it is possible to obtain from the examined structure any deterministic or random structure.

The computer complex may consist of computers with different structures. During the computing process, there must be an exchange of information between the various computers of the complex. If the computers are dispersed, located at different headquarters or at different command posts, for example, then the means of communication among the computers may become a bottleneck. One of the conditions of efficient operation of a computer complex is total coordination of the operation of all computers under the control of some central authority. All the computers should have access to long-term memory. For rational time distribution, the most important problem should be given high priority. Organization of the combined operation of a centrally located computer complex is essentially a technical problem (including deparallelizing of programs, dispatching, translation from one computer language to another, mutual control, etc.). On the other hand, organization of the operation of a computer complex with dispersed computers is to the same extent an opera-
national problem, since its solution is related to the operational capabilities and interests of the troops. There are many complex aspects of the current work of commanders and staff personnel, and therefore, it would not be wise to increase the autonomy that is fostered by distance and difficulty of personal communication. When we speak of a multicomputer complex we are thinking primarily of joint computations and not simply information exchange. The format of these computations should insure the most efficient utilization of the overall capabilities of the computer system in the interests of the entire set of problems, and not just each of the problems individually.
Chapter 12. Means of Interaction

... Sensation is actually a direct link between consciousness and the outside world, the conversion of the energy of an external stimulus to a fact of consciousness.

V. I. Lenin

Means of interaction are divided into three classes:

— Systems that enable people to conduct communications with each other over long distances (telephone, video telephone);
— Systems for interaction between machines designed for direct communication between equipment (computers, phototelegraphic equipment);
— Systems that enable man to conduct communications with a machine (mnemocircuit, speech recognition instrument).

The classical means of exchange of information between people are voice and written symbol.

Now there are electronic substitutes for pencil and paper. The equipment may include the following components: small computer, symbol generator, cathode ray tube, magnetic films, key control panel and typewriter keyboard. A high-resolution television camera is sometimes used. The information is stored in a storage unit and is read on an indicator (there is no need to turn pages). A light indicator is directed to any word or phrase, a button is pushed and the storage system reads out the additional information. The information is stored in the form of hypertext, i.e. a multilevel combination of letters and images (stationary and mobile). This makes it possible to find the required data quickly, using various levels of detailing of the concepts in hypertexts. The text is printed with the aid of a standard keyboard or stenographic apparatus.

In order to achieve effective interaction between man and computer it is necessary that man do the thinking and the computer do the computing. If the computer is used by several persons, one should not interfere with another. In particular, the central processor, which is designed for multilateral utilization, should be isolated from unauthorized interference from the outside. The ability of man to perceive and evaluate the intensity of different physical phenomena in nature should be
correctly considered. It differs substantially and depends not only on the sensory organs, but also on the properties of the nervous system. In order to double brightness or loudness it is necessary to increase intensity of light or sound by a factor of 10. However, in order to double an electric shock it is necessary to increase voltage by a factor of only 1.22. The dynamic range for auditory perception is 130 db, and for visual perception it exceeds 100 db. This signifies an ability to perceive sounds that differ in intensity by a factor of $10^{13}$, and light signals that differ by a factor of $10^{10}$. These are truly fantastic figures. Man can distinguish a discrepancy of 1 Hz at a frequency of 1,000 Hz, but at the same time he has very little capacity to distinguish more than 6 tones in the range of audibility when the range of these tones are presented to him individually. If one's speech is played back through earphones with a lag of 0.5 seconds, one may lose the ability to speak: this is related to the disorganization of the control system. The highest rate at which man can receive information is 6-8 bytes/second. According to certain data the transmission capacity of the visual system during pattern recognition is 4-10 bytes/second (according to other data it is up to 15 bytes/second). Theoretically the transmission capacity of the optic nerve is $3 \cdot 10^6$ bytes/second.

All of this should be taken into consideration during organization of the interaction between people and between man and the computer.

Voice, a symbol or a pattern may be a means of interaction.

Symbols are fed into the computer mechanically, by pushing a button, keyboard, or by writing text on some carrier.

The simplest data input and output device is a typewriter. Typing speed is usually 7 bytes/second. For typewriters with a ball typing element it is 20 bytes/second. Electrically controlled typewriters capable of speeds of 100 bytes/second have been developed; speed is expected to be increased to 300 bytes/second. This is quite fast, considering that the speed of reading orally from a sheet of paper is 15 bytes/second, and of reading to oneself—up to 50 bytes/second (an average of 30-35 bytes/second), while the speed of speech in dialogue is 6 bytes/second. Consequently information may be fed into the computer by means of a typewriter at the speed of dialogue, and it may be read out at the speed of reading.

There are alphabetical-digital printing machines that have an unprecedented printing speed of 2500 bytes/second. Several such machines (just like several typewriters) may be hooked up to the computer. Telegraphic apparatus or any high-speed telecode line may be connected instead of a typewriter. An optical device for writing information for input into the computer may have a speed of up to several million bytes/second. The input of a situation chart into the computer takes very little time (compared with the time it takes the operator to write the situation). In this connection, writing of a situation by hand becomes a bottleneck. Therefore, the procedures should be separated: the clean charts and the situa-

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tion are fed in separately. The computer itself combines the data in memory. The information capacity of interaction increases when generalized symbols are used. However, the memorization of conventional symbols requires skill. If the symbols in their combinations resemble a displayed object or process, express their essence in any way and evoke associations, they are easily assimilated and easy to use.

Symbols of this type include mnemonic symbols, through which are denoted the elements of military or technical structures, forming mnemonic diagrams. Mnemonic symbols and mnemonic diagrams play a particularly important role in military activity: a chart is a mnemonic diagram. Therefore, the question of the utilization of mnemonic language is worthy of great attention.

A mnemonic symbol consists of a signal element and details of external appearance. The signal elements may be any device with a controlled light output. Change of shape, brightness and color is accomplished by switching, by using remote controlled shutters or by changing electrical voltage. A mnemonic diagram may be used as a display unit and as a command console: mnemonic symbols may be used as command monitors. By pressing a button located in a certain place in a mnemonic circuit or on some mnemonic symbol, a preplanned command is transmitted to the computer or executing mechanism. The information capacity of a mnemonic circuit depends to a large extent on the rational separation of the displayed system or process into its elements and on the choice of appropriate mnemonic symbols for each element. The information capacity of a pattern increases as detailing increases, but because of the larger number of details its perceptibility decreases. The converse is true in the case of undetailed representation of a functional system. Consequently, excessive detailing or too little detail are undesirable: there is an optimum at which the amount of information that the operator exchanges with the computer or control system is maximized.

A mnemonic diagram should not tire vision or the psyche; the effect of routine, when individual mnemonic symbols begin to elude the attention of the operator, must also be avoided. A mnemonic diagram should be bright and expressive in order to attract attention continuously and for a long time, and it should be aesthetic at the same time. Mnemonic diagrams are effective for managing troops and systems in simple situations. They are constructed so that any substantial change of situation cannot remain undetected and reaches the operator in the shortest period of time. These qualities are insured by extremely high factorization of information: mnemonic diagrams display only the most important points that are stipulated in advance.

It is best to illustrate the capabilities and characteristics of mnemonic diagrams. Figure 67 (greatly simplified) shows a mnemonic diagram designed for controlling and directing the process of fuel and lubricant deliveries and consumption, and supplying an airfield network with
aviation fuel. This process is rather complicated since it depends on many unforeseen factors: the smooth functioning of the railroad system, the condition of automotive transportation and storage tanks, condition of pumping equipments, etc. (these have an influence on fuel deliveries); condition of technical flight equipment and airfields, and weather conditions (these have an influence on fuel consumption). The appropriate supervisor must see the entire pattern, make decisions and supervise their implementation. Forecasting is the most complex problem. In order to insure continuous railroad service, it is necessary to plan its operation at least three months ahead of time. At the same time, the number of flying days per quarter is difficult to plan in view of the inevitable errors in long-term weather forecasting. The initial uncertainty is compensated by control, which requires graphic and operational display of events. The characteristic feature of a mnemonic diagram is the fact that it displays not only the current state, but also all deviations from the plan, forecasts and disclosed deviations from the forecast. New decisions forwarded to executives and adopted by management, immediately lead to a change in the plan. This is accomplished with a computer. Any unexpected circumstances, such as violation of the railroad schedule, an accident at a pumping station or a forced landing, are immediately displayed on the mnemonic diagram. Mnemonic diagrams may be used effectively for controlling multiconnected technical systems with the aid of the computer by geographically-separated operators and operational groups.

The most recent achievement of technology is automatic recognition and imitation of human speech. The reproduction of speech in most languages requires about 100 typical phonetic elements (phonemes).

Affixal (formant) speech synthesis is based on automatic analysis of human speech and a compilation of an artificial vocabulary. Formants are component elements of speech, the natural resonances of the vocal system. They may be recorded and retrieved from memory by commands from the computer. Words and expressions are made up of formants. Speech may be synthesized according to printed text, i.e. by letters. A computer uses the formant library and studies the rules and limitations imposed by the language and speech formation. Speech may also be recorded in parametric form, in which the data are compressed. The computer "expands" the information to standard spoken form.

With a memory volume of $10^6$ bits, digital representation of a signal (by means of pulse-code modulation) insures a 20-second, formant representation—a 17-minute representation and printed text—4 hours of continuous speed.

The concepts developed by the computer are converted into sentences, words and letters; the letters are grouped into typical combinations and are converted by the computer into phonetic symbols, which are coded and, for verification, are compared with sample phonetic codes stored in the computer memory. The processed code acts on the voice imitator, where it is converted to speech. Combining such a system with a human
speech recognition device makes it possible to construct a conversational system of interaction with the computer.

There is another conversational system that includes an intermediate operator—a stenographer. The operator uses a special type of typewriter, the Stenotype. Because phonetic symbols have less redundancy, words and sentences can be abbreviated, and several keys can be pressed simultaneously, the speed of computer stenography equals the speed of speech, and if the stenographer is highly qualified, it is almost twice as fast as dictation. Considering the potential of the Stenotype, it may be assumed that it will afford an exchange of information with the computer several times faster than with another man. The computer deciphers the stenogram and inputs its information into the program; if necessary, the authentic text may be printed out.

An old adage states that "a picture is worth a thousand words." Any commander prefers to supervise combat action while observing the field of battle, and not while listening to reports. But this is technically possible only for commanders of small formations, and even then not always. Moreover, in the course of preparing various types of decisions, the observable part of the “battlefield” may shift. The physical picture contains many details which for a time may be considered as insignificant or even as interference. But as the action unfolds, these details may
acquire a different significance. The experienced commander recognizes what is most important and is not distracted by what is of secondary importance at a given moment. He knows how to switch at the required moment, however, and reevaluate the secondary information in order to pick out the important, and so on. Military people know how much a well-prepared and color-coded map—showing not only the main situation, but also all details—helps in operational work. Officers and generals rely on maps from the very beginning of their careers. A map is the commander's constant and true ally, but it is static, therefore, it does not contain enough information for modern conditions; a more dynamic display is required. Technology offers this advantage, but in order to take advantage of its capabilities it is necessary to become accustomed to the specific features of a dynamic display. For someone experienced, a real battlefield is an open book in which one may read nuances and difficulties of future conflicts. In the same way, a dynamic picture can provide an experienced operator with a mass of required information. The above statement is true for all forms of information: data about a military situation or logistics may be represented with all its dynamic changes and developments just as graphically as information about troop deployment.

Electro-optical devices have the greatest capabilities of all existing display systems. They are low-inertia, their image field may be changed in wide limits, and they may be used for forming any symbols, color and three-dimensional images. The main element of the cathode ray indicator is a cathode ray tube, in which an image is scanned on a luminescent screen by an electron beam, controlled by a magnetic or electrical system. The dimensions of the screen of the cathode ray tubes vary in wide limits from a few centimeters to one meter and more. The advantages of cathode ray tubes are their high resolving power and inertialess. The inertia of electron beams and phosphors may be reduced to microseconds, and therefore, the display process may be controlled by a high-speed computer. Color screens are informative and aesthetic. Digital printing and symbol storage tubes, known as charactrons, typotrons, compositrons, printoscopes, etc., are used for displaying symbolic and especially digital information.

Tubes that reproduce images of different tones and symbols simultaneously have been developed in recent times. Topological maps, charts, graphs, diagrams, and operational plans, with or without text, may be reproduced on such a screen. Some of the information of the image may be transmitted by communications channels, and it may come from computers, various sensors and technical systems; the rest is supplied by the operator (or several operators) using a beam pen. The image may be fed into the computer from punch cards, magnetic cards, magnetic tapes or any other recording devices, replaced in accordance with the program, or erased. Thus, the cathode ray indicator can combine three types of display:
—External information (reconnaissance information in the form of situation maps, information about headquarters operation in the form of structural diagram, typewritten text, etc.);

—Information produced by the computer (effectiveness evaluation results in the form of tables or graphs, diagrams, charts with variations of decisions);

—Information developed by the operators (in the form of decision variations, equations, graphs, etc.).

The computer should exercise full control of the display process.

Flat tubes, which may be seen from either of both sides, have come into use recently. In these devices the vacuum tube is made in the form of a box, and an electron gun guides the electron beam along the screen. The original design makes the tube compact and convenient for viewing; larger images may be produced (in comparison with ordinary tubes). Nevertheless cathode ray indicators are not very effective for group use, chiefly because of the limited dimensions of the screen. Therefore, a class of display devices with a large screen has been developed. A large image can be produced with the aid of television projection tubes, and laser, panel indicator and certain other devices. In projection tubes an opaque image (or one that absorbs light) is created electronically on a transparent screen, and the image is projected by means of a concentrated light beam onto a screen of any sort or size. Color images can be produced by using several tubes, illuminated by the primary colors and projected onto the same screen. The disadvantage of such devices is their comparatively low resolving power; in order to increase resolving power, it is necessary to solve problems encountered in the development of the corresponding electro-optics. The contrast of the image is also deficient.

High-quality images, with great detail and contrast, bright and pure colors, can be produced with the aid of lasers. Screen dimensions may reach 5x5 meters and more. Laser indicators are technically simple, since they do not require vacuum devices. Considering that one laser can generate different colors, it is possible to develop a color indicator with one laser. Here the rays of different colors are first separated to improve modulation and deflection, then they are recombined. Optomechanical, electro-acoustical and electro-optical light ray deflection methods are now known today, and the latter is the best one. Large scale laser indicators are very promising. Panel indicators represent a mosaic of discrete elements (or a solid screen), excited by infrared or ultra-violet rays. There are many substances that are capable of absorbing for a short time, and then of releasing for a longer time radiant energy, which has been converted to a different frequency (light). Images may also be erased. In certain designs, for example, afterglow is extinguished by infra-red rays, but if it is not erased, it will last for up to 20 hours. The duration of afterglow is controlled by constant voltage.

The range of application of panel indicators is limited by the excita-
tion light ray control systems. The problem of the development of a flat indicator, operating without an electron beam, is acute for many types of systems. Such an indicator has a matrix type screen, made of light-emitting elements. Each of them has a separate address, and therefore it is possible by switching the various elements around to produce any image. The elements themselves may have dimensions of the order of a fraction of a millimeter, and the distance between two different elemental centers is about one millimeter.

So far we have discussed only indicators with a flat image. The perception of a flat image requires additional mental power. One of the psychological effects consists in a unique reduction of versatility, descriptiveness, and "dimensionality" of thinking while observing a flat picture.

Three-dimensional indicators carry considerably more information. Three-dimensional indicators are classified according to the methods of data display as pseudo three-dimensional, imitative, illusory and truly three-dimensional indicators. Pseudo three-dimensional systems represent information in symbolic form by placing on a flat screen lines that create the sensation of perspective. An imitation of a three-dimensional image is made by using rotating or vibrating panels and screens and electro-optical systems with fixed elements. One of the principles of illusory three-dimensional display is described below. It is known that if an object is seen through a transparent medium, its apparent depth depends on the coefficient of refraction. Therefore, if a device with an electrically controlled coefficient of refraction is placed in front of a flat screen, it is possible to create the illusion of three-dimensional space. Stereo television systems are also illusory systems. They are based on a separation of images intended for the right and left eye by means of special orientation of the screen, construction of raster screens, use of polarized lenses and other methods. In truly three-dimensional indicators, a screen should take on the shape of the displayed object. It will probably be possible in the near future to control the shape of the screen by forming it in a liquid or gaseous (smokey) medium.

One can imagine four-dimensional indicators, on which processes that take place in time are displayed. Suppose that we are required to reproduce different phases of a battle. For this purpose we draw boundaries, arrows and numbers on a flat map. We can make a three-dimensional image of the terrain on a three-dimensional indicator and show various events on it by using colored lines, but this is not much improvement over the old method. It is possible, however, to create several three-dimensional images, corresponding to the different phases of the battle, and place them in different regions of the three-dimensional indicator or, even better, inlaid one in another. The combination of different colors and brightness makes it possible to distinguish the images that pertain to different moments of time. Such an image may be called four-dimensional with complete justification. Its creation requires painstaking and artistic work, of which the computer is more capable, since it
does not experience optical illusions. Probably nothing else can compare with a four-dimensional image in terms of descriptiveness and strength of impression.

A realistic approach to mass application of four-dimensional representation was opened by holography. A hologram is an interference pattern of light, radio or sound waves, scattered by an object, and imprinted on photographic film (or other recording device). If a hologram is illuminated with a laser beam we see the exact and complete three-dimensional image of the object, which may be viewed from different angles. A holographic picture may be very bright, and have contrast and color. Computer synthesis of a hologram of an object is a tremendous achievement, the scales of application of which are still difficult to assess. In just a few seconds the equations, formulas, statistical data, projections or diagrams of the object are converted to a form that is suitable for holography. The hologram is initially created in the memory of the computer as a set of points in three-dimensional space. Then it is converted to a series of two-dimensional images (projections), each of which represents a view of the object from a certain angle. The three-dimensional image is created by combining the projection; it may be observed in ordinary light. The object is accessible to 360° viewing. There is probably no advantage in displaying a large military operation in three-dimensional form. However, the organization of a proposed air battle is incomparably better observed and evaluated on a three-dimensional indicator. Suppose that holograms are made for various moments of time. Then they can be reproduced simultaneously in such a way that the passage of time will be represented on one coordinate of three-dimensional space. The operator can observe the unfolding of events at any speed he desires. Consequently it would be possible to display the course of events in a compressed time scale, so that the operator himself could change the speed of the image by backing up, going forward, in a word, so that the image would follow the train of thought. This is a four-dimensional indicator, probably the best one that can be imagined at the present time.

It should be pointed out that human thinking is more than four-dimensional. The development of events may be viewed in time and in space, from the viewpoint of different persons, under different conditions. Holography provides a means of reproducing spaces of any dimensionality, making it possible to examine the pictures of events and objects in different sequences and at any speed, to show them to colleagues, alter and reconstruct them, as desired. The overall promise of an increase in the information capacity of interaction and stimulation of thinking lies, perhaps, in this possibility.

Using a beam pen the operator may feed into the computer graphic data by means of forming new images (diagrams, sketches, contours and the like), as well as by correcting images displayed by the computer on indicators. Graphic interaction systems already are used extensively, and their potential capabilities are great. The computer rapidly reads a dia-
gram fed in by the operator, optimizes it and displays the new, corrected diagram. The advantages of graphic dialogue are especially great in regard to the combining of the computing and memorizing capabilities of the computer with human experience and intuition. The operator can concentrate all of his attention on the problem instead of working on calculations, requests and intermediate instructions. All of these functions are done by the computer itself. Man, however, draws slowly even with the aid of the beam pen.

One means of speeding this process up is to use oculograms—recordings of very fast tracking movements of the eyes. Eye movements make it possible to some extent to judge the direction of thinking. The periphery of the retina is designed for detecting objects, and the center—for distinguishing details. The eye focuses on the details of a pattern which for some reason attract attention. Analysis of eye motor functions yields data not only for the rational construction of an image, but also for understanding the process of assimilation and utilization of information. Eye movement during pattern examination can be established with the aid of special equipment. In order to maximize the productivity of the time and effort spent on image examination, the eye should stop at those places where most of the information is concentrated. It seems at first glance that this is what happens by itself, but the fact is that the situation is more complex: unimportant details may attract increased interest. Given the corresponding training and discipline, however, it is possible to coordinate the examination and contemplation of an image. Moreover, by thinking, it is possible to trace the movement of the eye (over a map, for example) behind the train of thought; if this movement is connected to a beam pen, it is possible to "trace" some symbolic pattern of the course of discussions and to feed it into the computer. If recognition is possible, then the rate of exchange of information with the computer (and perhaps between people) is increased by an order of magnitude. A new language of interaction may be invented, in the formation of which teaching machines may play an important role.

The material presented above represents the first steps in the development of a promising technique of interaction. Man thinks faster than he formulates a result, and exchange of information at the level of intermediate ideas and judgements is important for joint operations. It may seem paradoxical, but the information capacity of man-machine interaction (and consequently of group-machine interaction) will increase faster than that of man-man interaction, and in a short time the technical means of interaction will leave the natural communication modes (especially speech) far behind. When this happens, computers, equipped with corresponding accessories, will become an effective means of interaction between people. Who knows what heretofore unknown physiological capabilities will be discovered in man? One thing can be said: improvement of the technique and perception will be mutually stimulating.
Chapter 13. Data Retrieval Systems

... Having undertaken the most grandiose and difficult enterprises, be on the alert for all details but don't become confused and lost in them—see the trees and the forest, and practically every branch on every tree at the same time . . .

Ye. Tarle

Data retrieval systems offer reference information required for the routine activities of commanders and headquarters. All reference material is presently concentrated in the heads of the personnel and in documents; one must present a personal or written request in order to obtain required information. The amount of information that is stored in documents (instructions, plans, records, maps, charts, books, reports, etc.) comprises an infinitesimal fraction of the information that is stored in the memory of people. Nevertheless, it is sufficiently voluminous and very difficult to memorize. It is easier to use documental information than it is to question competent persons; it is easier to provide mass access to it. Sometimes we do not take into account how much this costs in terms of time and effort.

A commander is responsible for studying a tremendous number of documents pertaining to the various aspects of troop activity. He must write instructions, address and check them. Moreover he must be in touch with all new developments in the military and military-technical field and read many books and articles. But to know what should be read would require familiarization with the titles and abstracts of all books and journals that have been published. In order to make a specific decision the commander must have various reference information, and he does not always know the subjects on which this information is available in final form, which ones require additional processing, and on which subjects there is no information. The amount of information with which the commander must be familiar in order to find what he needs continues to increase. This situation is characteristic not only of the military, but also of any other activity. According to data of the Library of Congress of the United States, about 30,000 scientific-technical journals are now being published throughout the world, in
which appear anywhere from 0.9 to 2.1 million articles. In the United States alone, 100,000 to 150,000 scientific-technical reports are published, and this number is increasing by 30–40% every year. Up to 75,000 books on science and technology and more than 300,000 descriptions of inventions and patents are published worldwide every year. According to approximate data, the total volume of the world's scientific-technical literature doubles every 8.5 years. In the industrially developed capitalist countries there is one information specialist for every 20 scientists (and for every four in certain firms).

Even now, specialists in various sectors of the national economy must spend up to 40–50% of their work day on all forms of information activity, including the technological part of service correspondence (search, reception, logging, filing, distribution of documents). This does not include the reading of useful literature and documents. What time is left for work? And how much useful and even necessary material and data are not used at all simply because they cannot be found? It is no different in the military. And it is not the absolute figures (which are not identical in the various branches of service) that are important, but rather the trend toward an increasing volume of documents. The storing of documentary information on paper is undeniably an anachronism. Consider one example. The question of the transfer of an officer from one area to another used to require a request and some paper work, the participation of a few persons and a long time. Interdistrict transfers involved information problems. In order to choose a regimental commander it was necessary to analyze dozens of personnel files. Some of the files had to be acquired through the mail. But there was more to it than this: the selected candidate had to be replaced, and replacement involved new transfers, etc. There was no certainty that the choice would be optimum.

Now this may be done with the aid of a centralized information accounting system, in which sufficiently detailed information about all personnel is stored. Such a system must continually be complemented with current information about changes in service position, education, health, military achievements and successes, awards, punishment, etc.

Suppose that a military district needs a candidate for the position of regimental commander. A request is sent to the information system, indicating the following requirements: age, specialty, experience, marital status, desired travel distance, health, etc., everything that is required for the selection of a candidate. The system searches for the information and gives out several versions of transfer plans with consideration of vacancies that must be filled. Requests can be accumulated for a month, quarter or year and the transfer plans can be written in consideration of the arrival of inductees, new units, graduates of educational institutions, limitation on the total number of persons transferred, financial costs and transportation.

Such information retrieval systems are already in existence. For ex-
ample, the personnel accounting system in Belgium is being developed for the entire country. Data on 9.5 million Belgians will be stored in Brussels, and it is easier to inquire about them by telegraph from Brussels than it is to look for the information in a municipal archive. A central salary accounting system for 350,000 railroad workers has been in operation for 7 years in France. This system sends checks to each person through all bank branches in the country twice a month.

Consider a problem like the storage of topographical maps. It takes a long time to obtain a map of the required scale and region. It is necessary to determine the needed pages, sign them out from the warehouse, pick them up and paste them together. Then the situation, partially stored on other maps and partially contained in reports, must be inscribed on the map. An information retrieval system can find, on request, the required region and the scale, reproduce the map with the situation on a screen and, if necessary, photograph it and produce prints. All this takes place in a few minutes or even seconds. Orders, instructions and directives may be transmitted automatically via communications channels to any subdivision, reproduced on screens, read aloud and, if necessary, printed. There is no problem in providing key personnel with an automatic document familiarization system. It is hard even now to imagine that in a short time after the universal adoption of data retrieval systems (DRS)* not a trace will remain of the profusion of headquarters correspondence that required so much time and effort.

A diagram of DRS is illustrated in Figure 68. Requests are sent over telecode channels to the computer, which retrieves the information from the central library and prepares a reply. There is a system for storing requests, to which replies must be made periodically. A reply is dis-

Figure 68. Diagram of a data retrieval system: 1—communications center; 2—computer; 3—central data bank; 4—periodic request storage; 5—display system; 6—printer; 7—reproduction system; 8—peripheral systems.

* Soviet designation for data retrieval system (DRS) is information retrieval system (IRS).
played on a screen or is printed out. Several copies can be made, if necessary, with the aid of a special accessory. The central data bank is continuously renewed with information, and this should have no effect on the rate of servicing of requests. The set of peripheral equipment may contain a recorder, a small computer, and display and communications systems. The simplest peripheral equipment consists of a telegraph or phototelegraph apparatus. The communications channels are not elements of the DRS, but the DRS structure depends to a great extent upon them. The greater the centralization, the more effective and more economical is the use of automatic data retrieval systems, but more rigid are the requirements imposed on the communication network. The development of a branched and reliable communication network is a very expensive enterprise, but a justified one; if communications are poor then the DRS will not produce the required effect. Under conditions of mobile warfare and enemy counteraction, it is not easy to ensure continuous high-quality information communications. Therefore, the degree of centralization of the DRS and the makeup of the peripheral equipment must correspond to combat conditions.

All the information is stored in the DRS in coded form. Let us assume that the basic part of the activity of a commander and the forces subordinate to him is described with the aid of 10,000 ideas and mathematical expressions, and each specific action consists of not more than 10 combinations. Then coding of all the ideas requires 17 bits, and coding of all actions requires 170 bits. Considering that practical activity consists of not more than $10^5$ different one-time actions, we find that the memory volume required for storing the description of the entire activity of the commander does not exceed 17 million bits, a ridiculously small number. However, it is not meaningless. The question is this: is it possible to express military activity with the aid of 10,000 ideas, and if so, how?

Consider another example: Let us assume that we do not know how to operate with variations, ideas, categories or concepts. Nor are standard statements known to us; we can use the natural language in the volume of some imaginary course in military science, which contains 100 volumes, each with 25 printed pages, i.e., approximately $10^8$ letters or numbers. In order to write the entire course we need a memory with a volume of 0.5 billion bits (100 million bytes). The same course may be coded in somewhat shorter form. The Russian language uses approximately 100,000 words, and 30,000 words are sufficient for a military dictionary. If each word is assumed to have 5 letters on the average, then the course contains $2 \cdot 10^7$ words; coding with entire words requires $3 \cdot 10^8$ bits. There is nothing unusual about such a memory, and DRS can actually store everything that the commander and his staff need.

The basic requirements for a data retrieval system are rapid location, processing and display of the required data. For this it is necessary that
The system "understand" what data are needed, and language is required for understanding. The language for requesting information should be succinct and as precise as possible. These requirements are alternatives to some extent. The same data may be required in connection with different circumstances, and therefore the forms of requests may also differ. Let us assume that the information retrieval system has data about all aviators in the armed forces. These data may be required in connection with analysis of the combat readiness of the air force, personnel transfers, planning of recruiting for flight schools, planning for issuing uniforms, medical support, etc. Of course, not the entire set of data on aviators is needed by each user. In the planning of uniform issuance, for example, it is necessary to know the distribution of recruits by height and rank. In another case information may be desired about the number of pilots who will receive uniforms during the current year. It is impossible to store all data in the form in which they might some day be needed. Therefore, the DRS should process data in accordance with the content of the request. In some cases this processing may be limited to sampling of the required data, and in other cases additional computations are required. It is hard to imagine that all possible programs for which there might be a need at some future time would be compiled ahead of time and fed into the computer of an information retrieval system. New programs (at least simple ones) must be fed into the computer rapidly, and the program is transmitted, if necessary, via communication channels. The language of interaction with the DRS should be suitable for describing the program and the detail of the reply, and should ensure an acceptable processing time; the latter is important for correct request servicing priority.

A request itself consists of four parts:
- indication of the content of the information or address where the required information is stored; the first part of a request is called the address;
- indication of the required detail of the reply and scope of the reply;
- processing program or form of reply;
- time of reply (or priority index).

A data retrieval (request) language is devised in accordance with the classification of the information that is used in the DRS. The request language is usually a model of the natural language, simplified to the ultimate and preferably semantic, not requiring the transmission of grammatical structure or other features of language; it need only ensure comparison of the data stored in the memory of the DRS and of data indicated by the operator.

The chief difficulty is to express poorly formulated, obscure, incomplete and ambiguous ideas (and it will be this way if the requesters do not know what they want) in terms that ensure rapid retrieval of the
information in the data banks. The first requests usually approximate the true object, and only after familiarization with part of the information does it become possible to formulate the requirement in precise terms. If the reply to an information request is not a simple inquiry, then dialogue between the operator and the DRS is usually required. The request language should minimize this dialogue and ensure rapid convergence of the range of search and the actual interests of the consumer. A diagram of the establishment of mutual understanding between man and DRS is illustrated in Figure 69. All staff officers should know the request language. Otherwise the staff of servicing personnel of the DRS must include translators.

Let us consider the basic aspects of devising the address part of a request language. There are traditional and descriptor languages. The traditional languages are based on the same information classification methods as the alphabetical-subject, hierarchical and facet languages. These are the ordinary library, usually well known methods of grouping data. Descriptor language is based on key words. The basic semantic content of a request may presumably be expressed with sufficient completeness and accuracy by a short list of key words, i.e., words and word combinations most important for this purpose. Data processing and computing programs should have a classification or a code; indication as to the utilization of these programs should be included in the request. The operator cannot refer to the manual every time in order to find out if the proper program is in the DRS and what its code is. The DRS itself should find the required program and, if necessary, assemble it from several simpler programs. In order to do this the DRS programs are also classified. If the required program is not in the DRS, then it must be introduced by means of one of the algorithmic languages.

Figure 69. Transformation of a request.

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Industrial DRS usually do not perform functions of additional data processing and are limited to the readout of final data. For military DRS, most practical needs are related to a specific representation and interpretation of information. The compilation of a large program and its refinement is a long and laborious task, but any operator can learn how to write a simple program, especially on the basis of standard subprograms, and he completes it in a short period and uses it to great advantage. Consider this simple example. Let us assume that the enemy has constructed a new airfield, and we want to find out the regions of accessibility from it along routes which do not extend into the air defense zone. The algorithms for calculating the zones of accessibility may be available in the DRS, but not for the air defense zones in application to a specific range of air defense systems. The program for their calculation in ALGOL language occupies three lines of text and may be written in a few minutes; an attempt to solve the problem "manually" on maps requires several hours of tedious work, the result of which is of doubtful quality. As calculating programs accumulate in the DRS the need for the introduction of new programs decreases, but the classification of the programs, addressing of the required program and the putting together of a set of programs for servicing a complex request become more complicated. If a large program library is available, the choice of programs and determination of their operating sequence become an independent problem, which may require calculations. This problem is best entrusted to the DRS, but the operator must precisely formulate it and express it in request language. Accordingly, the request language should be expanded in order to encompass control of the programs. It may be simpler sometimes to enter a small program along with the request than to determine its presence in the DRS, its address or index. We see that the more problems we desire to turn over to the DRS, the more complex the request language becomes. But new methods may be worked out during the adoption of the DRS to facilitate understanding of the meaning of the request, and in accordance with these methods, we come upon new ideas for improving the request language. Moreover, the development of the computing part of the DRS should compensate for the complexity of the language in such a way that it can easily be used. This may be achieved by transferring some of the request formulation functions to the DRS itself.

One way of accomplishing such transfer is to use tolerance, the similarity between terms of a natural language. Suppose that for the position of squadron commander we need a pilot with a higher education, younger than 35 years, and with the rank of major. The DRS stores lists of servicemen, but it cannot do a consecutive search through the entire personnel roster. The request may be written in terms of tolerance\(^1\) indices: "higher education." "major," "younger than 35." The

\(^1\)The relation between certain objects is called tolerant if it is reflexive and symmetrical.
DRS itself writes the retrieval program in terms of these indices. Calculation shows that the writing of such a program and its implementation require approximately 10 times fewer operations than successive search through several tens of thousands of people. In order to acquire reference materials that are stored in final form, not requiring additional processing (cards with text, microfilms, etc.), we may use a simpler mnemonic language that does not involve the use of computer technology.

An encoded description of data, the text of a document or map, is called a retrieval pattern. Data retrieval consists in comparing retrieval patterns stored in the memory of the DRS with requests fed into the DRS, checking the correspondence between them and making a decision concerning whether or not to issue a given document. Depending on the request language and method of collating retrieval patterns, various coding methods are employed: digital, symbolic or other (for example, coding can be done with dark or light rectangles, which are printed for identical retrieval patterns in such a way as to produce a uniform dark field). Charts with retrieval patterns or their microcopies are stored in memory. Perfect correspondence of the codes of the stored and requested patterns is not mandatory; a certain degree of similarity is sufficient. Retrieval patterns and their microcopies are usually stored in a separate memory system with rapid access. Each retrieval pattern has an address, according to which the required material is found after collation of the request pattern and the retrieval pattern and establishment of the correspondence between them.

Figure 70 shows a generalized diagram of a DRS, in which no additional data processing is provided, but only delivery to the requester. The DRS has two types of storage systems: active and passive. Active storage is intended for locating retrieval patterns of documents (text materials) along with the documents themselves, their microcopies or the addresses of documents (or their microcopies) that are in the passive storage unit. Information retrieval is accomplished with the aid of the active storage system and the computer. The passive storage system is used for storing materials and their microcopies. All forms of electronic memory, as well as cards with drawings and text or microphotographs, may be used for active storage. Optical-mechanical systems are used for rapid access to the card and photographic memories. Passive memory may be constructed on any means of data storage: books, card files, photograph files, etc.

Systems that perform additional processing of data obtained by request are constructed somewhat differently. First, on the basis of a request, the data that must be retrieved from the data bank are determined. This problem should be solved by the computer. A request, in addition to the basic requirement, should contain the program, according

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to which the requested data are narrowed down. After the data are retrieved from the data bank, they are encoded and fed into the computer, where they are processed. The reply is printed out. The processing may show that there are not enough data; then the composition of the data is corrected and the request is repeated. Such DRS are specialized computer complexes.

Among the most important means of data retrieval, in terms of a request, are frequency dictionaries. A frequency dictionary gives the frequency of usage of terms in certain types of text (semantic content). A request is analyzed from the point of view of key words (which determine the content of the text) and the texts in which these words are used most often are located in the memory of the DRS. These texts will contain the basic information corresponding to the request.

The information is compressed in order to simplify the storage of data in natural language. Special methods make it possible to reduce the volume of natural text by one order of magnitude and more, although in view of elimination of redundancy, errors (random and

Figure 70. Detailed structural diagram of a DRS: 1—converter; 2—passive storage; 3—active storage; 4—operational storage; 5—input system; 6—input converter; 7—request input; 8—request converter; 9—operational storage; 10—computer; 11—output converter; 12—output system; 13—operational storage; 14—computer; 15—output converter (reset).
grammatical) take on deciding importance. Serious attention should be devoted to error correction methods.

Let us try to imagine what data retrieval systems for military application may look like. Various requirements are imposed on DRS, depending on the scale and the required operational capability, and accordingly the hardware will also differ. By way of example we will consider the following characteristic types of DRS: large-scale, individual and educational.

Large-scale DRS should have high-capacity central equipment, a large number of peripheral points, and a branched communication network (Figure 71). The more functions that can be turned over to the DRS, the more economical it will become. The central data bank should be separated into thematic headings, such as operational work, combat training, personnel, logistics and transportation, technical equipment and operation, etc., in order to improve organization and training and to facilitate the hooking up of new subscribers. These headings should have both general and independent access. Most of the data that might require additional processing in the computer should be stored in the electronic memory. The reference part of the information, which does not require processing and is displayed graphically, may be stored in discrete or continuous photographic memory in the form of microphotographs, slides and motion picture films. These include geographical and topographical maps, book library, tables of the performance characteristics of weapons, officer personnel records, rosters and records of enlisted personnel and noncommissioned officers, etc. The central data bank is an independent DRS capable of supplying reference material.

The next major element (subsystem) makes up the computation center (CC). The CC must fulfill three types of work: computations on the basis of prepared programs and data which have a direct input; development of new programs according to requirements; computations requiring the utilization of information from the central data bank. The CC has its own permanent storage (with a volume of 0.5-1 billion bytes), in which the most frequently used and renewed data are stored.

The third element (subsystem) is the communications center, where the data input and output systems, display, recording and data transmission systems are concentrated. The function of the center is broader than usual. The computer controls the communication center effecting coordination of all systems in the center, distributing the flows of input and output data in accordance with the addresses and servicing priority, switching communication channels, and establishing servicing priority. The display systems allow immediate viewing of information on screens if there is no need for printed documents. Each basic component of the system has its own computer. All the computers are interconnected and form a single computer complex. It is also possible to build one computer with sufficient output, combining all functions.
The servicing personnel of the central station perform three functions: technical operation, monitoring of requests and assisting in their compilation, and input of new information. The peripheral points are basically of the same structure as the central one, but all the components are represented in correspondingly smaller dimensions. All the peripheral points should be directly closed on the central point: there should be no intermediate stages, but the communication channels may be switched. Considering the various conditions of troop activity, both in peacetime and during war, the peripheral points should be arranged in such a way that they can be used as central points in the event that some part of the forces become isolated (due to the breakdown of communication lines or for any other reasons). In addition, each peripheral point should operate within certain limits as an independent DRS. This pertains especially to operational work. There is no pressing need to solve problems pertaining to personnel, logistics, financing and accounting, therefore, it would not be advisable even in the interests of autonomy, to duplicate the information at the peripheral points. The communications system should have sufficient transmission capacity and automatic documentation. Magnetic tapes of meetings, personal or telephonic, should be viewed as legal documents.

We now proceed to the priority system of the DRS method of processing requests. We will assume that one of the military units and has received new materiel (aircraft) and needs information on operational experience and combat deployment. The corresponding instructions were provided, but the instructions alone are insufficient. The commander
writes a request in descriptive language in approximately the following form: “aircraft (type); give data: properties; counteractions; application; experience; problems; training.”

The request is fed into the peripheral DRS; first a response is worked out on the basis of local data, and then the refined request is sent to the central DRS. The information is returned in the following form: a) references to articles or pages of books; if required, microcopies, which may be mailed and destroyed after use; b) condensed excerpts with drawings, tables and diagrams, which are transmitted via communication channels. If the district DRS does not have complete information, it in turn transmits requests to the units and organizations of the district which have experience in this matter, and also to other districts and to the center.

Let us consider another example. A training plan for development of interaction must be worked out. A request is made for lessons of this type. The initial request may be written as follows: “lessons of the last 5 years; location; date; name; project.” According to this request the DRS gives out data relative to lessons of this type, conducted in the Soviet Army and abroad. After studying them, the operator selects those which are of interest to him, determines what needs to be clarified and repeats the request. The DRS finds all the information or forwards the request to the center and offers the user the information in the requested scope and form. It may be a detailed description of some lesson, or statistically processed data on a group of lessons, or a generalized version of training program. The next request may concern details such as the makeup of designated enemy forces, or the structure of an umpiring apparatus. Such combined operation of the operator with the DRS promises to be fruitful. The operator may check the novelty of his plan and the level of organization, and he may also take advantage of the experience of others.

The DRS of an individual installation, operating independently, should be organized somewhat differently. Here the DRS performs an entire set of information problems related to military training and combat operations. Let us assume that the discussion concerns a ship. The DRS is an important component of the weapons system on which combat successes and the fate of the crew depend to a great extent. Being independent during sailing time, the DRS may include the following:

—reference military technical library;
—reference navigational library;
—all operational documentation that may be required at sea;
—all current information about combat and engineering systems of the ship;
—all information pertaining to economic support;
—information about personnel.

The DRS should have a center and peripheral points. All computer equipment, data storage systems and data processors are located in the
central part; the peripheral points contain the data request and display systems. It is usually not difficult to provide highly productive communications systems for the DRS, and therefore peripheral computers are not needed. The peripheral points are located at battle stations, on the bridge and at other key points on the ship. The DRS performs not only information functions, but also control functions, the following in particular:

- processing of current information from navigational instruments and course plotting;
- course calculations by assignment;
- placement of the ship on the required course;
- solution of combat problems related to the main combat activity;
- control of ship air defense systems;
- processing of radar, sonar, visual observation data and display of current situation on screens or on request;
- control of communications systems;
- distribution and redistribution of resources;
- control of ship systems, etc.

It would be more correct to call such a system an information control system (ICS) rather than a data retrieval system. The language for communicating with the ICS should be sufficiently complete, but at the same time laconic and operative. There is not enough time for long dialogues with re-requests, and therefore the operators must have perfect mastery of the descriptive language and of the control language. In this sense the navy has experience, namely signal language.

The need to utilize written (textual) documentation is worthy of serious discussion. The ritual requires written text for instructions or directives. Thought should be given to how proper this really is. Text recorded on magnetic tape has the impact of a written document but then hearing time is considerably less than reading time, and many people can hear at the same time. It is not difficult (and it is high time) to break the habit of using written documents, and this is desirable for saving time under conditions of maximum stress. Since all combat and control systems are closed on the ICS, and all information from military commands to regulations on the implementation of cultural-mass measures is transmitted to the ICS, the functional responsibility of the system is great. The combining of various functions entrusted to the ICS has an effect on technical implementation, algorithms and programs. The priority servicing of requests and multiprogrammed processing in the computer complex take on special significance. The basic difficulties involved in the development of such systems are not technological, but pertain to software (especially language) and mastery of the DRS by operations workers.

The primary task of a DRS of an educational institution consists in the support of the training process. A training process, as is known, requires the solution of several technological problems, each of which requires
reference information. We are discussing the writing of schedules, allocation of lecture-halls, organization of groups, cost accounting, etc. The entire problem can be solved successfully with the aid of the DRS. There are other functions related to decision making in problems of training programs, organization of training and independent work of the instructors and students. The DRS should solve all bibliographic problems, assemble literature on request, and produce thematic abstracts. This we have already discussed. The development of programs and distribution of training hours require (in addition to great military science erudition) special knowledge in various fields of science and technology and familiarization with a great deal of literature. The foundation for programs are the general state of a scientific discipline, requirements of the troops and experience in the operation of educational institutions of similar profile, both of our armed forces and of foreign armed forces. Work on programs proceeds continuously, but there are stages when something must be changed radically. It is especially difficult to include in a teaching program a new course or subject: the question of what to exclude always arises. Educational institutions usually maintain close contact with their graduates, departments and troops. Critiques are received which, in particular, contain indications of gaps in the education of graduates, and new requirements. Systematization and generalization of these critiques are the task of DRS.

The literature in various fields is continually enriched, new fields appear and the horizons of the known fields are expanded. The DRS should have a program which analyzes these data and, in accordance with certain criteria, yields information relative to the formation of such branches of science as require examination from the standpoint of their inclusion in a training program. These data are compared with the requirements of the troops and other users. The outdated and little used sections of courses are identified on the basis of analysis of the responses of graduates and incoming scientific literature. Comparison is made with the programs of other educational institutions (including foreign ones), information about which is fed into the DRS, and recommendations on how to improve the programs are worked out. A concise summary of the requirements, state of the science, and quality of the current training program is written. Instructions, which the DRS uses for preparing variations of program correction and time distribution may be written on this basis. The importance of training programs in the preparation of military specialists and the influence which these specialists will later have on the troops are so great that no organizational or technical efforts in this area can be considered excessive. The DRS, of course, cannot yet be taught to monitor the development of scientific disciplines and the level of education. The task of the DRS is to process and display information in a form suitable for mental assimilation, comprehension and evaluation. The correct decision must be made during the process of
creative discussion among competent persons (this is the case when dis­
cussion is indispensable). The problem here is for each member of the
group responsible for developing training programs to assimilate all the
information, and not just a part of it; otherwise discussion may be futile
and the decision random. This cannot be done without the DRS, or
preliminary purposeful processing of the information.

No less important is the problem of organization. The specific organi-
zational feature of an educational institute is that it is very unwilling to
change in some ways, but efficient to the utmost in others. The depart-
ment faculty structure has been around for centuries, but teaching groups,
and study, field and laboratory groups are changed once or twice every
year. The problem consists in the optimum combination of stable, fun-
damental forms of organization with flexible, efficient ones. In this con-
nection, it is necessary to make organizational decisions that take into
accounts the results of training, state of training and employment of the
teachers. This also represents a tremendous volume of information, which
may be processed by the DRS.
Chapter 14. Automation Complex

Thoroughly develop fundamental and applied scientific research and introduce their results more rapidly in the national economy.

From Resolutions of the 24th Congress of the CPSU

1. Outline of Technology

We will try to imagine how the technology for utilizing an automated complex should look. The assumptions will contain a certain amount of imagination and the description by necessity will be fragmentary and extremely simplified.

The commander’s order of operations will not necessarily coincide with the order described below. Certain functions may seem to be unnecessary, certain others will be altered, and new functions will appear. We are interested in the use of automated means, and only from this point of view will we examine the commander’s work.

The commander arrives at a new assignment and, after becoming familiar with his deputies and closest associates, he embarks on a task of situation analysis. All the required factual data can be obtained from the data retrieval system (DRS). Data about the grouping of forces in the area of combat operations are displayed on the general situation screen of the command post; first in small scale: the enemy, our forces, neighbors, communications; and then in larger scale: the enemy disposition of troops, lines; fighting strength; and finally in large scale: enemy strong points, his weapons, state of communications. Documents are requested, which contain quantitative data on the makeup of enemy units, characteristics of his military equipment, military experience, and morale, as well as lists and combat characteristics of the command staff. If there are no data on certain questions, these questions are directed to the intelligence branch for the collection of additional information.

The commander then undertakes initial familiarization with his own troops. Using the DRS and interaction with his closest aides, he becomes familiar with the disposition, makeup of troops, weapons, equipment,
data on combat capability, combat readiness, political-moral state of the personnel, and the combat, political and psychological characteristics of commanders directly subordinate to him. Some of the questions for which there are no data are directed to subordinate troops and staff sections for clarification. Formulation and description of the present and the future missions of higher headquarters are displayed (on the indicators). Then the commander may become familiar with previous events. If necessary, the course of combat actions in a given region can be reconstructed on the screen (in convenient time scale). Proposed, but unimplemented decisions are noted. This phase of operations ends in familiarization with current combat orders and instructions, logistics, and contact with subordinate commanders of various ranks and neighboring units (automatic communication and data display are used here).

The next step is to analyze the theater of military operations (terrain). Photographs of various battle areas and the surrounding sectors are displayed by stereoscreen. By changing the scale and foreshortening, the commander can acquire the most informative representation of the data, which are simultaneously supplemented with digital data and text. The commander and his aides analyze the terrain, weather situation, geophysical conditions; using highly informative means of interaction he asks questions and receives answers. The subordinates, in turn, direct the commander's attention to details which they think are important. The mission assigned to the troops is shown on large-scale stereoprojections of the terrain.

This phase is concluded by posing a number of questions, the answers to which require a computer complex. These questions basically concern possible variations of combat actions, logistics, preparatory measures and their organization. The purpose is to concentrate on those questions which arose in the commander's mind as a result of his initial impression. Some of the points are specific in character: prepare mathematical data, evaluate the effectiveness of certain measures and actions. Other points are more general: propose solutions for problems and sub-problems, forecast the situation, evaluate the enemy's intentions. Even the most general points must be distinctly formulated with specific limitations, in a quantitative statement if possible: suggest solution variations of a rigorously formulated problem, submit a forecast and intentions relative to certain factors. There should not be questions such as: “What does the enemy intend to do?” Instead, ask: “What is the probability that the enemy will attack at sector A within the next 2 days?” The answer may be approximately as follows: “For the next 2 days the enemy may concentrate such and such forces in sector A; the effectiveness of attack is such and such, the probability of attack is such and such.”

Having formulated the questions and designated the time that he wants the answers, the commander may visit his troops for on the spot familiari-
zation with the situation. In this stage of the operation the automated systems of subordinate units are used.

In the next step, the commander returns to his command post with new ideas and impressions, and begins to make decisions. But first he listens to and discusses the answers to questions previously asked (including new questions that arose during his visit to the troops). He makes his initial information decision relative to the situation, state of enemy troops and his own troops. On the basis of the information decision (which is passed on to the subordinates) and mission, assigned by the senior commander, he formulates his initial ideas of an operational decision. The commander briefs headquarters on the overall objective of the forthcoming battle and conducts discussion. Automated systems make it possible to recruit a supervisory staff from the field. The suggestions are fed into the computer for evaluation and utilization by headquarters and services for the preparation of their proposals.

The next step may be characterized as the discussion stage between the commander, staff and services. Background reports are prepared; the computer evaluates the proposals made during the “brainstorm,” analyzes them, separates the constructive ideas and uses them for preparing alternatives of a decision. Key personnel formulate their own ideas and proposal, and feed them into the computer for subsequent combined analysis.

The most important step is decision making. It may begin with an examination of alternative decisions of the computer, which are displayed automatically for review. Each alternative is accompanied by a list of positive and negative features, and effectiveness evaluation. Discussion of the alternatives includes indication of weak spots, alteration of limitations and input of additional data into the program. The discussion is conducted with the aid of highly informative means of interaction, and the DRS records new proposals. As a result, some of the alternatives are discarded, some are improved, and new alternatives are developed. The discussion continues until only one alternative is left, which is approved, or else the commander selects one of the alternatives, alters and improves it (using the automated complex) until he considers it to be the best one.

The decision is sent on to headquarters for detailing. One aspect of detailing consists in mathematical modeling of the forthcoming battle as a whole, of its elements and individual logistical aspects. Modeling makes it possible to consider the influence of random and secondary factors that escape the field of view during general examination, and also to evaluate the effectiveness of the designated measures.

We have examined one rather arbitrary version of the decision making process. All other areas of technology should implement the principle of allowing commanders and operators to spend the maximum time and effort for creative work and direct command of troops. Otherwise, it
is impossible to implement the directive of the Minister of Defense, Marshal of the Soviet Union A. A. Grechko:

"The commanders and headquarters at all levels will creatively solve problems of combat readiness, and concentrate their attention on the most important and long-term trends on which depend our superiority over a probable enemy. Their thoughts and efforts should be focused on the search for new capabilities and alternatives for continuously increasing the fighting power of the Armed Forces." 

2. **The Consultant [Konsul'tant]**

As seen from the material presented above, the information functions of the commander and staff play a great role in decision making. The collection, selection, systematization, interpretation and presentation of data require a great deal of time and effort. These are consultative functions and they can be automated. An electronic consultant, depending on the organizational level, may have different dimensions. Judging by known foreign models, a rather large DRS can be housed in one rack with a desk of ordinary dimensions and may encompass transcription and operational reports. A useful DRS with low information capacity is easily made portable (in a field pack). A small DRS, containing an electronic scratch-pad memory, retrieval computer with display and push-button programmed control, is quite adequate for current operational work and may become a reliable "constant companion of the commander." The small DRS should be connected periodically to a large one (directly or through a communication channel). It is essential that the commander personally (and not through delegated persons) use his own DRS, change programs and monitor the informational completeness of his consultant, treating it as a personal weapon, as a means of expanding his own memory and sensory organs. Only in this case can it be effective. Other key personnel may have their own small DRS of the same design, but with professionally oriented information.

DRS, like people, should interact with themselves and with people in order to understand each other and continually renew their information resources. DRS are easily made to "forget" (much easier than man) unnecessary data. They readily receive new data, but continuous monitoring of this process is required.

A considerable advantage of the electronic consultant is the fact that it can be entrusted without danger with random thoughts, instantaneous ideas and considerations that appear promising; it does not distort or forget them, does not confuse the address and stores them until they can be developed, used or discarded. The consultative function of the

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automated complex should embrace all aspects of activity. When we speak of an automated complex we do not simply mean the DRS alone. We are talking about the entire set of automated systems that support military organizations. If only the commander has a DRS there is little to be gained: an isolated island of automation is nothing more than an exotic entourage in the complex technical equipment of an army.

The strength of automation lies in the complex, the systems approach, and in interaction and mutual information. The memory of DRS is limited, regardless of the level of microminiaturization, both technically and in terms of content, since this memory is made up by the people who use the DRS. But life is always deeper and more complex than can be foreseen, especially by one man. In judging collective activity we established that the development of complex problems requires a collegial structure. This conclusion is also valid in relation to automated systems; a system of compatible and constantly interacting DRS is very effective.

The consultative functions of the DRS should not be limited to reference functions. The computer of the DRS should be used for doing calculations related to the display of information and evaluation of effectiveness. The volume of operations which can be carried out in this regard by the retrieval computer of a small DRS is low, but the requirements here are correspondingly limited. The position of the electronic consultant in the decision making system is illustrated in Figure 72. Here the operators are released from reference work and calculations; this increases their creative capabilities.

Figure 72. Diagram of an electronic consultant: 1—reception, processing, and presentation of data on the enemy and operational conditions; A—reconnaissance operators; 2—reception, processing, and presentation of data on friendly forces; B—operators; 3—display of combined information on the situation; C—situation analysis and preparation of alternative decisions operator; 4—effectiveness analyzers and comparison of alternatives; K—commander.
This plan is based on the utilization of automatic data collection and display systems by operators. Interaction between the operators is based on evaluation and improvement of the decision alternatives developed by them. The main operational function of the computer is to evaluate the effectiveness of the alternatives. It is assumed that reconnaissance data and data about our troops will be processed by different operators. The combined information about the situation is formed on the basis of data selected and appropriately processed by the operators and the computer. This information is used by the operator who prepares decision alternatives. The commander may not only correct the decision alternatives, but also feed into the computer other alternatives which will be evaluated. Thus the DRS not only gives information, but also develops new information (estimates).

It is often necessary in military practice to evaluate many alternatives, each of which may be described in sufficient detail, but in view of the very detail of description it is necessary to resort to unwieldy calculations in order to arrive at an evaluation. Such a “rash of alternatives,” when “alternative after alternative was proposed . . . and after heated discussion was thrown out,” is described by Marshal of the Soviet Union A. A. Grechko. During the Great Patriotic War, one could not determine whether or not various alternatives were “unrealistic, both from a military theoretical, as well as a practical, point of view.” There were not enough calculations that could be done only by the simplest means and they were not good enough for making definitive conclusions. It took a great deal of time, effort and valuable talent on the part of high-ranking military chiefs to arrive at such conclusions. The electronic consultant not only eliminates these worries, but just as important, it provides the foundation for thorough examination of plans of action, careful situation analysis, determination of obstacles and ways of overcoming them.

3. The Assistant [Pomoshchhnik]

The electronic consultant does not perform decision preparation functions, let alone decision making functions. In order to help the commander and his staff in the performance of these functions, it is necessary to develop a computer section and means of interaction between the automated complex and the corresponding control links. Then the electronic assistant will be capable of independently working out proposals and justifying them. The decision to adopt or not to adopt these proposals is the responsibility of the commander or other key personnel. Proposals may pertain primarily to information decisions. Control of the parameters of the information decision preparation program (input of

1 A. A. Grechko, Bitva za Kavkaz (Battle for the Caucasus), Moscow, Voyenizdat, 1967, p. 242.
2 Ibid.
weight coefficients for various sources of information, limitations, etc.) is the responsibility of the operator, but all data processing and evaluation of the reliability of decision alternatives are entrusted to the electronic assistant. Proposals may also pertain to organizational and operational decisions, but we may speak here only of certain fragments, and not of complete decision alternatives. The alternatives of operational and organizational decisions (as well as the making of information decisions with consideration of the computer alternatives and their justifications) are developed by the operators. The effectiveness evaluation and optimization are performed by the automated complex.

The programs and data of the "assistant," to a greater extent than of the "consultant," are individualized and specialized in accordance with the personal features of key personnel, character of the groups, and general arrangements made within a given group. The "assistant" requires more continuous combat evaluation, supplementing of programs, revision of old data, and continuous direct interaction. Cooperation between people and machines, just as between people at headquarters, is essential.

The development of automation is aimed at the reassignment of information, computation and evaluation problems to computers. If an electronic assistant is available, the commander and the operators may direct almost all of their efforts into the creative channel since they have all the necessary data for this purpose and are not distracted by secondary problems.

The position of the electronic assistant in the decision preparation scheme is illustrated in Figure 73. The electronic assistant is assigned additional functions of working out information decisions and optimization. The alternatives of operational and organizational decisions are prepared by the operators. They control the actions of the electronic systems and can actively intervene in their work; the extent and the result of this intervention are recorded and are made known to the commander in order that he can know exactly what aspects of the situation were contributed by the operators. Through electronic systems, the commander may influence the work of the operators, suggest ideas to them and cooperate with them in any project. Reliability evaluation, along with effectiveness evaluation, is not the concluding, but an intermediate result of the work, the guiding factor and stimulus for improvement of the decision. The functional structure of combat evaluation is continuous here, i.e., the operators theoretically can work without the aid of the computer (if they have the know-how). But the advisability of an action, then reliability evaluation or effectiveness evaluation will indicate information or operator B proposes an infeasible or irrational alternative actions, then reliability evaluation or effectiveness evaluation will indicate this. Control is not absolute; not all errors are detected since the program does not guarantee coverage of all decisions which man is capable of thinking up. But continuous improvement of the programs should mini-
mize such cases. In this regard creative thought should be developed in consideration not only of the features and characteristics of subordinate key personnel and groups (to which we are all accustomed), but also in consideration of the features of the electronic assistant. The utilization of the electronic assistant does not merely simplify and facilitate work, but also enriches it with new qualities and possibilities. Alternative decisions are developed by people (except for information decisions, where this is not mandatory), but their evaluation (and consequently their quantitative justification) and the improvement that can be achieved within the framework of the logic employed, are entrusted to the computer. The system cannot operate independently (without operators); its functional structure is fragmented.

It should be recalled that an automated complex embraces not one command post, but rather a system of interconnected command posts; in this regard, the structure illustrated in Figure 73 should be related to other analogous structures. An informational connection is required here, and not an operational one: compared with the “consultant,” the “assistant” should have not only larger computers, but also permanent lines of communication with the corresponding transmission capacity and high reliability. This does not mean that it is useless or impossible.

![Figure 73. Diagram of an electronic assistant: 1—data on enemy; 2—development of informational decision on enemy; 3—data on friendly forces; 4—development of an informational decision about friendly forces; 5—optimization; 6—presentation of data; 7—reliability evaluation; 2—effectiveness evaluation; A, B—operators; K—commander.](image-url)
to automate only one or a few command posts (and not all at once). However, the full effect can be achieved only through a computer complex because we are concerned not only and not so much with the convenience of operation as with the quantitative evaluation of an idea and the essence of a decision; this can yield the greatest benefit if the evaluation is done in all interconnected links because it is impossible to perform the entire volume of work in one (even higher) link. The lower-level links of the control system can be equipped later with systems that convert the "consultants" into "assistants"; the reequipping process may take a long time. But after it is completed the "assistant" of the higher-level link may be used in the entire system of interconnected command posts. This is desirable since it enriches computer programs and encourages interaction. The automated complex is constructed by the hierarchical principle, and all the operational information circulates in this structure. This ensures the preservation and total utilization of the data. The structure should be highly reliable and viable.

Combining the "consultant" and "assistant" in one complex gives the operations staff time for clear thinking after having requested information and having loaded the computers with work.

The electronic assistant gives complete analyses and accurate evaluations.

Analysis must be especially detailed and thorough when new forms of weapons are used or when weapons are deployed under atypical conditions. An evaluation of only already-available alternatives is not enough here; it is necessary to find weak spots, and to aid in the determination of the directions of future creative search. Analyzing the Novorossiysk offensive operation during the Great Patriotic War, Marshal of the Soviet Union A. A. Grechko emphasizes the joint ground and naval operations. This operation may be regarded as a complex situation. Here is how A. A. Grechko describes this situation:

"Thanks to the accurate artillery fire, it was possible to destroy the enemy's engineering fortifications. Powerful artillery bombardment made it possible to land forces in the port of Novorossiysk quickly and without great losses.

"The intelligent combination of the elements of surprise (with respect to time, location and extent of the front of the landing forces) and the application at that time of a new method of massive deployment of torpedoes against coastal installations and fortifications stunned the enemy, scattered his forces and prevented him from quickly organizing a strong counteraction at all points.

"The Novorossiysk offensive operation had several important features. Thus, the dispersion of the forces of the 18th army of Tsemesskaya Bay, limited access roads and directions, and the small areas of the initial regions dictated the choice of the directions of the main and supporting
strikes. These same circumstances influenced the composition of forces and equipment required for carrying out the operation."\(^1\) The Novorossiysk operation verified the fact that all branches of services may be used in moderately rugged mountains and large cities.

No less characteristic in this regard was the activity of the commanders of the individual groups that carried out the combined operational mission, but which were located in tactical isolation. The leadership of such groups required the ultimate utilization of creative abilities. Analyzing a similar complex situation, Marshal of the Soviet Union A. A. Grechko wrote: "... The army commander (he is speaking of the actions of the 56th Army in 1943—V. D. and D. K.), on 17 September ordered the troops, pursuing the retreating enemy, to organize attack groups in the main directions. Their mission included: penetrate the enemy’s defense at his intermediate positions and by wedging into the rear, cut the enemy’s escape route and destroy him unit by unit. The army commander, taking advantage of the fact that the enemy did not have a continuous front, ordered mobile detachments and machine gun groups to courageously penetrate to the enemy’s rear with the mission of creating panic in the enemy’s defense, and paving the way for the advance of strike groups in the main directions."\(^2\)

In situations of this type the electronic assistant may be an indispensable means of creative interaction among commanders and of operational cooperation among them under conditions of an uncertain situation, dispersal and surprise.

4. The Comrade-In-Arms [Soratnik]

The electronic assistant is not capable of independently proposing (let alone making) operational and organizational decisions. Figure 74 shows an automated complex which performs the entire sequence of decision preparation decision making functions under the continuous control and with the participation of the operators who can use the computer results in any stage, feed in new ideas or corrections, but who are not required to participate in the development of the computer decision.

The diagram shows three channels: two resolving and one teaching. One of the resolving channels is an automatic computer channel, and the other is a “heuristic” operator channel. The computer channel analyzes the input information and information decisions, prepares alternatives of operational (organizational) decisions, selects criteria, evaluates effectiveness, and optimizes a decision.

The operator channel performs the very same functions. Crossed inter-

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\(^2\) Ibid., p. 383.
action is provided between the resolving channels: the output of each unit is connected to the next unit, both of its own and of the next channel. The operators can use all means of automation for consultation and assistance, but the decisions are worked out manually. The final decision is made by the commander in consideration of, or on the basis of, the results produced by both channels: “willful actions” in the computer channel are replaced by “threshold action,” comparison of the output values with the thresholds or of several values. The thresholds are established ahead of time, but their values may change, depending on the results of the operation of the operator channel. Consequently, the computer channel carries out a willful action, formulated ahead of time or during the operating process. The teaching channel is designed for building a thesaurus in the channels and for training them in problems of increasing complexity. The teaching problems should consider new achievements in military science, the requirements of practice and the future. Teaching includes the formulation of such problems, analysis of solutions, disclosure of deficiencies, development of instructions to the combat team at the command post, and introduction of changes in program. The operators of the second channel cannot be given this function: performing the analogous function, they inevitably would insist on their ideology and methodology, alter the computer channel to their liking and eventually transform it into their own pale copy. The special group, assigned to teach the system, will teach and improve itself, discover new,
often unexpected results, find the reasons for their appearance and think up new problems.

The three-channel structure ensures the independence of formalized (traditional), and intuitive (creative) methods of decision preparation and teaching. The basic concept is to ensure, in any case, a timely workable decision, and if an original, creative decision is worked out, to consider it also. The combined analysis of the decisions worked out by the two channels can stimulate a more effective decision which the commander proposes. The teaching group is very important. Its role consists not only in the continuous correcting of programs and training operators, but also in the implementation of a certain operational ideology, organization of improvement, cooperation and mutual stimulation of the algorithmic and heuristic channels.

The main advantages of the system are mutual stimulation of the channels and mutual control. The operator can propose the most improbable decision without risk of consequence: everything is subjected to at least a double check. Competition between the channels and the presence of different alternatives suggest new ideas to the operators. The interaction of the channels reduces the decision preparation time. The automated complex, embracing the entire system of command posts, does not have to contain electronic comrades-in-arms in all links. Perhaps at a certain stage it will be necessary to have “consultants” in some (obviously low level) links of control, “assistants” in higher-level links, and “comrades-in-arms” in the highest and most important links. The use of “comrades-in-arms” in lower-level links at the present stage of development of technology is fraught with enormous problems in the design, adjustment and improvement of a multiconnected system that includes people; a system which must operate in a stressful situation with an acute shortage of time. These, however, are temporary problems.

With high information communication channels, the electronic comrade-in-arms may service (at least through the computer channel) lower-level organizations. Therefore, the automated complex as a whole expands its its comrade-in-arms functions to all organizations, in spite of the fact that the technical equipment of the lower-level control links may remain at a lower level for a long period of time. It is difficult to predict the future competence of the electronic comrade-in-arms and how great an influence it will have. It is clear, however, that a workable decision is always ensured, and that the creative energies of the commander and his staff will be liberated to the maximum extent from technological functions. Teaching and self-teaching of the “comrade-in-arms,” expansion of its thesaurus and programs will be accompanied by a general improvement of means of automation and development of group intellect.
Conclusion

The scientific technical revolution has embraced all fields of human endeavor, especially military. The appearance of modern weapons systems with great destructive yield made the work of the commanders and supervisors at all levels exceedingly complicated. The time allowed for preparing decisions was cut sharply and the responsibilities of the commanders for their decisions increased immeasurably.

The future development of military and technical systems will bring about an increase in the volume of information that must be received and processed for decision making. **Military activity requires that a scientific approach be taken to the solution of both theoretical and practical problems.**

"The scientific approach presumes the purposeful planning of scientific work in the interests of concentrating our main energies on the solution of basic fundamental and applied problems; research for the purposes of developing new weapons systems and military equipment, the most effective means of utilization of forces and systems in combat, of operations in war as a whole; the search for progressive forms and methods of training and teaching army and navy personnel; rapid adoption of the results of research in military practice; timely generalization and dissemination of past experience in combat, political and operational training of troops and staff personnel.

"It must be thoroughly understood that today there is a new relationship between science and industry, and science and military practice. In addition to transformation into a direct productive force, science also occupies the position of one of the most important factors in winning victory in a modern war.

"The scientific approach to the solution of all problems of military construction has become the ruling requirement of our time."

In a complex situation, the most effective decisions are those which are based on long-range concepts, engendered by knowledge, military talent and creativity.

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In addition, the decision preparation process always includes technology not related to creativity, but requiring great expenditures of time and energy: processing, condensing, conversion and display of information, various calculations on resource distribution, evaluation of effectiveness of military actions, etc.

The volume of technology steadily increases and is beginning to exceed the information capabilities of man. This can be counteracted only by the extensive, universal application of means of automation, which can perform all technological operations involved in preparation of decisions.

The chief material-technical factor of automation and the scientific-technical revolution is the computer, which is undergoing rapid improvement. During the last 2 decades there have been three generations of computers. The fourth generation is now being adopted and technology stands on the threshold of the fifth generation of computers. Any person can make direct use of the computer, and this has a deciding influence on the entire nature of military activity. The computer will become as commonplace as the telephone and will become an aid to man in creative labor.

The use of remote control panels and block programs will enable the computer to operate in the conversational mode and at even higher speeds. World-wide there are many systems, presently under development, that are designed for such a mode of operation and for using general languages that approximate the natural ones.

The adoption of automated systems is a complex and painstaking task in which there are many creative offshoots, but there is even more routine labor. First and foremost, this is practical work.

The methodological foundation on which automation is built requires scientific substantiation and detailed development. It is unique and cannot be limited to the reproduction of human behavior.

Science must introduce clarity, strictness, discover the laws of processes and phenomena and, in the final analysis, perfect the concepts in the interests of practical application. This can be achieved through exact knowledge. Automation can be effectively adopted for practical purposes only with a thorough knowledge of science.

Automation of the technological part of the decision preparation process is only the first part of the problem. Much more important and promising, but incomparably more complex is the second part of the problem, namely automation of creative work.

The general methodology of problem solving requires intensive development. This is particularly true of the theory concerning the solution of incompletely defined problems. A general theoretical base must be built and the methods must be defined: classified, detailed and transformed into computer programs.

Programming requires the development of a mathematical tool and,
perhaps, the development of a new tool, whereby qualitative factors may be included in the analysis.

As the theory and techniques are improved, and as experience accumulates, the level of creative processes will rise because of the fact that the part of the problems previously considered creative will be thoroughly analyzed and solved and will become routine, technological problems. Their solution will be turned over to computers. This will save manpower and time. Some of the liberated forces will be used for formalizing and developing creative problems, with the result that they will become accessible for computerized solutions; the rest will be diverted to expansion of the scope of creative activity.

Human creative capabilities will increase and expand as man is liberated from technological functions and the results of solved problems are turned over to computers.

By developing new problem solving systems and improving them, man himself will undergo development and improvement.

Not excluded is the fact that this development will take place not only by using the vast functional reserves of the brain—whose true capacity we cannot yet determine—but also by forming new physiological resources, changing the morphology of the brain, and resulting in a purposeful, possibly, very rapid evolution of the brain. This process may have a favorable effect on the entire biological species.

It is difficult to imagine such a grandiose prospect, and one of the tasks of science consists in conducting research in this area.

The processing of information at the conceptual level will become a routine activity in the very near future. Thanks to automation, collective thinking will become a potent factor in progress. The combined experience, group activity and intellectual integration of commanders, operators and engineers in situation analysis and decision making will immeasurably enrich human capabilities and will create new prospects for progress.

Creativity will always precede technology, just as art precedes craftsmanship.

This process, like any search for truth and perfection, is interminable and inexhaustible.