F. Zwicky and A. G. Wilson (eds.): New Methods of Thought and Procedure. Contributions to the Symposium on Methodologies, May 22-24, 1967, Pasadena.
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Fritz Zwicky: Prologue, 1-4

There have been numerous attempts throughout the recorded history of man to review, classify and systematize the basic methods of thought and of procedure which are being used to deal both with the practical and the theoretical problems of life.
To mention a very few of these there are the ORGANON of Aristotle' s, the NOVUM ORGANUM by Francis Bacon and the Discours de la Méthode by Rene Descartes. These works were, of course, based on knowledge available at the time, which was both limited and in many cases false.
Since the treatise of Descartes was written, science, technology and life in general have become so complex that renewed meditation on the essential aspects of fundamental constructive thought and procedure is in order. The necessity for such meditation has obviously been recognized in many countries and in many quarters and has in some instances led to a successful reevaluation of old principles and procedures as well as to the development of new thoughts, while again in other cases a lack of perspective resulted in more confusion.
To achieve technically and humanly satisfactory results three prerequisites must be fulfilled, namely *first unbias*, that is absolute detachment from bias and prevaluations, *second*, sufficient *knowledge* about the true nature of the world and *third, freedom of action*. These three conditions have seldom been fulfilled in the past, today we have hopes of achieving them.

Perhaps the most far reaching and successful effort of all times which did satisfy all of the mentioned prerequisites is the idea which was promoted by Henri Pestalozzi (1746-1827) and first practiced by him - that knowledge must be made available to every child and adult. Pestalozzi is thus the initiator of general education, some of whose ideas were so profound and far reaching that even today they have not yet been sufficiently taken advantage of inasmuch as we have not yet achieved the training of the *whole of man* which he visualized.

To go back to World War I, those who lived through it, well remember the general gloom all over the world and also the ardent desire by many of the best minds to understand what had gone wrong and to develop universal vistas and to devise methods of thought and procedure which would enable man to deal more effectively than before with the ever multiplying complexities of life.
As a result the world was completely remodeled through the planned actions of communism, of the Versailles Treaty, of the League of Nations and the advents of Fascism and Nazism. The nations which remained free likewise started on many planned developments of their various potentials and they in particular recognized the need of organizing and integrating their scientific and technological capabilities. Institutions like the brain trust of the New Deal thus came into being and were subsequently diversified and expanded manyfold during the Second World War in order to insure the defeat of the dictators.

Since World War II enormous efforts have been made to develop general methods of thought and procedure which would allow us to deal efficiently with all of the complex problems of the world and which would eventually enable us to reach that most desired goal, a unified world based on mutual respect and esteem of all men and of all nations. The United Nations, the agreements about Antarctica, about nuclear testing and most recently the Outer Space Treaty resulted from these efforts. In addition, literally hundreds of groups all over the world were established for the purpose of applying their technical and human knowledge toward the construction of a sound and stabilized world.

By way of illustration I shall mention a few groups of which I have some personal knowledge since it has been my good fortune to have been associated with them.
For instance experts from all fields were brought together by the ingenious founder of the Pestalozzi Foundation of America, Mr. H. C. Honegger, to establish war orphan villages on all continents and to deal effectively with the problems of destitute children all over the world.
In way of large scale constructive actions for adequate housing the efforts of Professor Constantinos Doxiades in Athens are outstanding, partly because of the yearly Delos Conference which he has organized and in which experts in absolutely every field of human endeavor participate. The establishment of the Cité de Généralisation du Canisy near Deauville, which is being promoted by the French, is intended for occupation by experts and men of universal outlook who will deal with large scale problems, one after another.
The Conférence des Sommets (Cultural Top Conference) in Brussels in 1961 should also be mentioned. At the invitation of the King and the Belgian Government, outstanding representatives of all sciences, technologies and the arts were invited to attempt an integration of all essentials of present-day knowledge. The organizer of this conference, Francois Le Lionnais, president of the French association of scientific writers, had previously edited a book, LA METHODE DANS LES SCIENCES MODERNES, which may be regarded as a sequel to Descartes' "Discours de la Méthode" and which contains articles by some forty authors.

Finally, we organized the Society for Morphological Research, one of whose purposes it is to bring all new methods and procedures to the attention of a larger public. In this endeavor two major projects have been started, namely

1. A series of some two dozen comprehensive volumes on new methods of thought and procedure in the sciences, engineering, medicine, law, and the arts and so on.

2. To arrange conferences periodically at which the experts of the different methods and procedures will be brought together for discussions. Along this line a first proposal was made several years ago to Dr. A. H. Warner, then Director of the Office for Industrial Associates at the California Institute of Technology. After Dr. Warner retired, the project had to be postponed but is now being realized in this symposium through the cooperation of Richard P. Schuster, the present Director of the Office for Industrial Associates.

The purpose of the present symposium was to awaken a universal self-awareness of methodology as a discipline. Dr. Simon Ramo in his inaugural address expressed the belief that such a trend in thinking is already discernible and will develop more or less automatically. However this may be, those among us who are active in the invention and application of new methods of thought and procedure want to make sure that all knowledge gained is effectively integrated and widely disseminated.

As Professor Henry Borsook of the Biology Department of C. I. T. stated in his introduction of the session on morphological research there has been nothing like this since the latter part of the 5th century B. C. in Greece. At that time there was a great outburst and activity in the subjects of logic, the nature of knowledge, its transmission, exercise of power and the use of it. While the Greek atomists were intensely interested in the facts of nature, the sophists taught techniques, how to be successful politicians, lawyers, generals, ignoring, however, moral considerations. Justice for them was nothing more than the interest of the stronger. Thus knowledge without wisdom produced some monstrous consequences. On the other hand the wisdom without empirical knowledge of Plato's Academy could be nothing but ineffectual.

Today, after a period of more than 2000 years of accumulation of disconnected thoughts and procedures we are attempting to integrate them and to make them available to every man, woman and child for the purpose of *training the whole of man*.

THE MORPHOLOGICAL APPROACH TO DISCOVERY, INVENTION, RESEARCH AND CONSTRUCTION, 273-297

ABSTRACT

The morphological approach to discovery, invention, research and construction has been conceived and developed for the purpose of dealing with *all* situations in life more reasonably and more effectively than hitherto. This is achieved through the study of all relevant interrelations among objects, phenomena and concepts by means of methods which are based on the utmost detachment from prejudice and carefully refrain from all prevaluations.

Applications of the morphological methods of the total field coverage, of negation and construction, of the morphological box and others to technical problems in particular and to human problems in general are described. These not only illustrate how discovery, invention and research can be conducted most effectively but also how the morphological approach makes possible the clear recognition of those fatal aberrations of the human mind which must be overcome if we are ever to build a sound world.

A. The Origin and Development of the Morphological Approach

During the past five thousand years men have fought five thousand wars, more or less. In spite of all of the talk about progress we are still at it, fighting, murdering and destroying. Many other ills, some major and very many minor ones, confront and bother us in addition and seem to get more difficult to handle as time goes on.

Grave problems related to the growth of the world's population remain largely unresolved. In spite of the fact that many of the plagues which formerly decimated humanity have been checked, the overall state of the physical health of men hardly shows much improvement. The mental aberrations of individuals and of peoples clearly seem to be on the increase. Generally life has become so complex that we find less and less time for deep contemplation and happy creation and recreation. Regrettably, science and technology, in the hands of irresponsible, weak or selfish men and exploiters have vastly contributed to the ills of the world, rather than to their elimination or sublimation.

Under these circumstances a thorough reappraisal of the overall conditions of the world and of man's place in it appears imperative to all who hold that a more satisfactory state of affairs can only be reached if each individual and each race has the opportunity and the means to realize its own inherent genius without having to fear the ever continuing inhibitive or destructive interference of other individuals and races.

Two principal goals must be kept in mind if we are ever to achieve a sound society living in a sound and beautiful world. First we must see to it that conditions do not further deteriorate. To achieve this, a *universal holding action* is necessary in order to preserve at least the most satisfactory aspects of the status quo. Secondly our mental *world image* must be set straight and enriched, so that we may clearly visualize the true interrelations among all things, material and spiritual. And thirdly we must proceed with planning and construction which is inspired and guided by truths thus visualized rather than by disregarding them.

In order to achieve all of these goals we must conceive of an approach which allows us to implement and to integrate our knowledge of all of the essential interrelations among the physical objects of the world and the physical, chemical and biological phenomena which govern their interaction. And further we must clearly

understand the nature and interplay of the ideas, concepts and actions of men.
With these goals in mind, the *morphological approach* was conceived which concerns itself with the development and the practical application of basic methods which will allow us to discover and analyze the structural or morphological *interrelations among objects, phenomena and concepts*, and to explore the results gained for the construction of a sound world.

To give a concrete illustration for these thoughts , a complex task may be mentioned with which we concern ourselves for instance within the International Academy of Astronautics. The legal-scientific committee of this Academy is studying the morphological aspects of *Justice in the Space Age* [1] [6], including both *outer and inner space*, which latter is the space below the surface of the Earth, both its interior and the ocean depths. Our ultimate goal is the formulation of a treaty which will be adopted by all nations. Before we can hope to achieve this, a *universal holding* action must be organized, agreed upon and enforced.
For instance, we must prevent all and any possible large scale contamination of the oceans and of all natural life within them. Nor can we tolerate any explorations and operations within the interior of the Earth which would endanger any stretches of the land on the surface. Likewise, in outer space we must see to it that no irresponsible damage is done to the Moon or other bodies of the solar system.
Both the holding action and the formulation of a successful treaty for inner and outer space require a comprehensive integration and evaluation of all present knowledge about the physical world as well as about the positive and negative intentions of men.
We are furthermore badly in need of observations and analyses of basic facts as yet unknown but suspected, and we must in particular try to visualize the possibility of new devices, the invention, construction and use of which might completely alter the course of the destinies of men and of nations. For instance if nuclear fusion of any common materials, such as ordinary rocks were achieved by a group of scientists in some specific country, the rest of us might be forced to accept a treaty about the future of inner and outer space as dictated by those in power in that particular country.

Obviously, the members of the International Academy of Astronautics, as well as all men of good will and sound mind will spare no effort to keep themselves informed on all scientific and technological progress, or, as we morphologists express it, on all new *pegs of knowledge*. Such information will be indispensable if we wish to construct for our good use a *world image* which is true in the sense that it will enable us to fully comprehend and control the happenings around us as well as those within us. The visualization of this true world image can guide us on sure paths to discoveries and to basic inventions and, last but not least it will enable us to *predict* correctly the course of future events and to adjust our actions accordingly.

It is my considered opinion that among all of the methods of thought and of procedure the *morphological approach offers us the greatest guarantee* for success in our endeavor to construct a *true world image* and to make effective use of the information embodied in it for the elimination of all human aberrations. These, in the past have been the cause of most major human tragedies and they have prevented us from recognizing and constructively promoting the *genius of man*.

In order to demonstrate the unique usefulness and power of the morphological approach we now proceed to describe a few of the most effective methods which have been developed and applied, making use of morphological thinking. In each case we shall briefly mention some of the specific results achieved. For further details we must occasionally refer the reader to the existing literature.

B, Some Characteristics of the Morphological Approach

1. Totality Research and Unbias*

(*Detachment from Prejudice is the indispensable prerequisite of the Morphological Approach. Since the English language does not have any single words for the opposite of bias and prejudice I propose that the word unbias be introduced.)

As we have stated already, the morphological approach aims at an understanding of all of the interrelations among objects, phenomena and ideas and concepts in ever widening complexes of human life and of the world as a whole. It insists on visualizing all of these interrelations without prejudging the values of any of them. Utmost *detachment from prejudice* is the first and foremost requirement of the morphologist. It must be emphasized that such freedom from prejudice is far more difficult to achieve and to live up to than most men might think.
Anyone who has tried it will certainly have found out that, in order to remain free and to continue to act truly independently, he must be determined to go it alone if necessary and he must be able to persist, even if no recognition is forthcoming and even though abuse and criticism may be reaped instead of rewards.

2. The Scope of Morphological Research

Since the morphological approach uncompromisingly proceeds to explore *all phases of life* and *all aspects of the external world* it does not take anything for granted which has been done in the past.
The morphologist always starts from the beginning, no matter what the problem or the task at hand may be. On the other hand, regardless of how thorough any previous study, investigation or action appears to have been, he will always go beyond the stage where others have stopped. As one French writer expressed it, the morphologist is the *specialist of the impossible* [2]. Let me briefly sketch two examples which illustrate these aspects of the morphological approach.

a. The Conversion of Chemical Energy into Kinetic Energy of a Missile

For decades, and even for centuries projectiles and missiles have been launched through the release of chemical energy, making use of either guns and rockets, although the thermopropulsive efficiency of both devices is miserably low when compared with what should ideally be possible. According to the fundamental principles of thermodynamics, if we let the chemicals A, B, C, etc. react to produce the substances A', B', C', etc. the difference Δ = – ' released by this reaction at constant external pressure can be extracted as useful mechanical or electrical work or energy.
Here is the total free enthalpy of all of the reagents A, B, C etc. and ' is the free enthalpy of the reaction products. By definition it is = E - TS + pV, where E and S are respectively the total energy and entropy of the system, while T, p and V are the temperature, the external pressure and the volume.
If, as an example, we consider the well known reaction $2H_2+O_2 = 2H_2O$ we find that per mole of H_2O formed the free enthalpy Δ = 56. 7 kcal is liberated at SPT. This amounts to 3. 15 kcal/gram = 13. 1 X 10^{10} ergs per gram of the original propellant mixture being available for transformation into useful mechanical or electrical energy.
This means that by reacting one gram of the gaseous mixture of $2H_2+ O_2$ to H_2O at constant pressure, we should be able, theoretically, to accelerate a projectile which weighs one gram to a speed of 5.1 kilometers per second. Or, using n grams of one of the conventional chemical solid or liquid propellant mixtures or explosives the free enthalpy released (which is of the order of 2 kilocalories per gram) should allow us to launch a one gram projectile with a velocity of about $4\sqrt{n}$ km/sec. Now it is a well known fact that the maximum muzzle velocities of guns are only about one km/sec, *no matter how much gun powder we use* for each shot, that is no matter how great the number n is.

And the thermopropulsive efficiency of rockets, especially that of multistage rockets is poorer yet. For instance, to get one gram of a payload off the Earth into interplanetary space requires theoretically 6 X 10^{11}

ergs (plus an additional amount of a few per cent to compensate for the frictional losses of the large rockets in traversing the atmosphere).
In present day practice of launching spacecraft as the final stages of multiple rockets, per gram of payload 100 grams of propellant are needed which release a useful energy of 100×10^{11} ergs. Over 90 per cent of this available energy is therefore wasted in the conventional types of rocket launchings of artificial satellites and space capsules.

Engineers and scientists who have occupied themselves with the theory and practice of launching missiles either from guns or by means of rockets will no doubt object that, although the principles of thermodynamics admit of the full conversion of the free enthalpy released into useful work, this can be achieved in practice only under very special conditions.
For instance, if a chemical reaction is reversibly carried out in an electrolytic cell (power cell, propellant flow battery) the energy of the generated current will be very nearly equal to the full value of Δ released, provided that the current intensity is very small. This current, or the electrostatic potential energy of a condensor which is charged up by the reaction in the cell can be used subsequently to accelerate a small "missile," for instance a charged colloidal particle with a minimum loss of energy.
Most specialists in the field, however, seem to be under the impression that the thermopropulsive efficiency of large scale conversions of chemical energy into kinetic energy will, in practice, never approach the theoretically possible values and must actually remain at the miserably low level of the rockets of today. They consequently appear to have given up all hope and have made no efforts to think any further.

But the morphologist will not let himself be stopped by any of the conventional objections. He will emphasize the importance of one of the most fundamental directives of the morphological mode of life which holds that *nothing should be accepted as impossible unless it is clearly proved to be impossible*.
As a consequence he will attempt to visualize all of the possible ways of converting chemical energy into kinetic energy. In parenthesis I like to point out that comprehensive reviews of this type are seldom given in the textbooks or in lecture courses, although they would be highly instructive. The teaching profession in science and engineering should seriously occupy itself with this subject and explore it in all of its vast aspects. Here I must restrict myself to a brief sketch of some typical considerations which have led to rather startling results.

Returning to the fundamental aspects of our problem of the conversion of chemical energy into kinetic energy we must first attempt to achieve a total perspective over the geometrical, dynamical and chemical characteristics which may be involved in the construction of launching devices.

Starting with the *geometry* of possible launchers we see that there are two principal bodies involved, that is the missile M and the propellant or explosive P. A tube T may be needed in addition to act as a container or as an initial guide. We further designate with V the arrow which indicates the direction of the velocity with which the missile is to be launched. Considering only M and P, three typical locations of these two bodies with respect to the arrow V are possible. These are shown in the diagrams 1a, 1b and 1c.

Diagram 1

[redacted]

The first arrangement a) schematically represents the initial locations of the propellant and the missile within a gun, the *missile being in front*. This method of launching has the drawback that no muzzle velocity can ever be achieved which is materially greater than the average thermal velocities of the molecules of the reaction products at the peak temperatures reached after the explosion of the propellant charge.
For molecules such as N_2, H_2O, CO_2 as they are released by the common chemical explosives these velocities are of the order of 2 km/sec. Once the projectile has reached this speed it will not be accelerated any further since the molecules are too slow to follow and cannot transfer any more forward momentum to the missile.

The *second* arrangement b) schematically represents a rocket, the *propellant being located within the missile* itself. Rockets can be accelerated with optimum propulsive efficiency relative to any given inertial reference system Σ only at the moment when their forward velocity with respect to Σ is exactly equal and opposite to the velocity u_e of their exhaust gases with respect to the same frame Σ. For smaller and for greater values of v the propulsive efficiency decreases rapidly and becomes zero for both v = 0 and for v = very large compared with u_e.

If we designate with M_o the mass of an empty rocket and with M_p the mass of the propellant loaded in it, we may accelerate the rocket in vacuum from standstill to a maximum velocity v_{max} which is given by the equation (1)

$$v_{max} = u_e \log_e (M_p + M_o)/M_o \qquad (1)$$

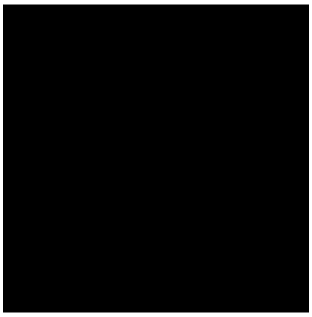
For a high energy chemical propellant the exhaust velocity is of the order of u_e = 2.5 km/sec. To achieve therefore in vacuum a terminal rocket velocity of v_{max} = 11. 2 km/sec, which is equal to the escape velocity from the Earth we must react 88 grams of the said propellant per each gram of the empty rocket. Ideally, however, less than 20 grams should be necessary if we also remember that the combustion of the propellant would actually produce a higher exhaust velocity than u_e = 2. 5 km/sec if the whole of the available free enthalpy had been transformed into kinetic energy of the exhaust gases.
Under the best conditions, and using a high energy propellant capable of producing the assumed exhaust velocity we therefore can achieve escape velocity only with a thermo propulsive efficiency of less than 20 per cent.
For multi-stage rockets the losses are still greater since the empty cases of the initial boosting rockets will be jettisoned into space with considerable kinetic energies with respect to the frame Σ, relative to which the missile was launched. This energy is entirely wasted, in addition to that carried away uselessly by the exhaust gases of the various stages.

A thorough scrutiny of the potentialities of both of the arrangements a) and b); that is of the gun and the rocket does not leave us with any hope that a particularly more complete conversion of chemical energy into kinetic energy of high velocity missiles can be accomplished with their aid. There thus remains only the possibility c) of positioning propellant and missile, as shown in diagram 1.

The *third* arrangement c) of placing the *propellant in front of the missile* would at first sight appear to be completely hopeless if not utterly stupid. This is no doubt the reason why it has never been even given any thought.
Remarkably enough, however, once one decides to explore its possibilities seriously he not only begins to visualize an unexpected number of devices but, among them also various types of launchers which are potentially capable of working with the greatest thermopropulsive efficiency.

Some devices of the type c) are as follows.

) The propellant P may be placed in front of a missile M which lies on a disk D fixed to a spring S which is attached to a solid wall representing the reference system Σ. (Figure 2) On explosion of P the spring will be compressed and on its rebound propels M in the direction V. This launching device works in vacuum, in air or under water. Many variations are imaginable inasmuch as the energy released by the explosion can be stored temporarily as gravitational, electric or magnetic energy, rather than by a spring.



) If our device is in the atmosphere we can dispense with the disk and spring and put M directly on the wall. The explosion of P will be followed by an overexpansion of the air in front of M which thus will be propelled in the direction V by suction.

I leave it to the reader to amuse himself with the invention of many other possible launchers in which P is placed in front of M. Among these one of the most promising is the following.

) The tube-duct launcher

To achieve maximum propulsive efficiency the propellant P, which is at rest with respect to M at the start must be picked up and accelerated by the missile itself in such a way that the work W done in this process is stored temporarily, through stagnation compression for instance. On reaction of the compressed propellant W will then be released together with the originally available free enthalpy Δ from P.
The liberation of $\Delta + W$ will generate an exhaust velocity u_e which increases with the forward velocity v of the missile, rather than remaining constant throughout the flight as in ordinary rockets.
An aeroduct (ramjet) or an aeropulse [3] which can slide along a closed launching tube filled with a gaseous propellant is suitable as a missile which will "swallow" up P and store the energy thereby expended through compression in the stagnation cross section. The exhaust gases will remain at rest with respect to the launching tube (Σ) and will not carry away any kinetic energy as in the case of rockets [4].

b. Nuclear Fusion Ignition

Much work has been done on the possibility of nuclear fusion within constricted plasmas. Although the liberation of nuclear energy through the fusion of light elements into iron in ordinary rocks for instance would perhaps represent the most important technical achievement of all times; no concerted effort seems to have been made by anybody to review *all imaginable processes for igniting nuclear fusion in common materials*. This task, which obviously necessitates a morphological scrutiny of a totality of phenomena has deeply interested me for many years.
Of the results I have arrived at I can mention here only the idea of accelerating small solid particles to velocities of up to 1000 km/sec. Such particles, impacting on rocks for instance, could generate temperatures of hundreds of millions of degrees and readily ignite nuclear fusion.
This suggests an auxiliary morphological study, analogous to the one presented in the preceding section a) of the various devices which might be capable of producing very high speed particles. This study is now so far advanced that I am inclined to predict that the ignition of nuclear fusion in common materials will be achieved in the not too distant future.

C. The Morphological Methods

As I have already stated, the morphological approach is based on an attitude which uncompromisingly and inexorably pursues its quest for all of the interrelations among objects, phenomena and concepts without permitting the interference of any prejudices or rash prevaluations.
In order to achieve these goals morphologists have developed and applied a number of powerful methods of thought and of practical procedure. Among these we mention the methods of the morphological box, of the systematic field coverage, of negation and construction, of the method of the extremes, the reasoning and action by analogy, the various procedures of generalization and of successive approximation, the principle of the flexibility of scientific truth, the principle of perfection and imperfection and others. In the following we briefly sketch some of these methods and a few of the results achieved.

1. The Method of the Morphological Box

We proceed as follows.

First Step.	The problem which is to be solved must be exactly formulated.
Second Step.	All of the parameters which might enter into the solution of the given problem must be localized and characterized.
Third Step.	The morphological box or multidimensional matrix which contains all of the solutions of the given problem is constructed.
Fourth Step.	All of the solutions which are contained in the morphological box are closely analyzed and evaluated with respect to the purposes which are to be achieved.
Fifth Step.	The best solutions are being selected and are carried out, provided that the necessary means are available. This practical application requires an additional morphological study.

The method of the morphological box has been used with great success for a comprehensive review of propulsive power plants and propellants [3], for the enumeration and analysis of all of the processes that can be applied to individual nylon fibers (in connection with the invention of the curly yarn and the famous Helanca fabrics), to all of the processes that can be used to produce the curly yarn, to the construction methods for straight lines and plane surfaces, for the invention of composite analytical photography [5], the totality of all possible energy conversions [6], the collection and shipment of scientific journals to warstricken scientific libraries [6], the problem of bothersome inquiries [5], rock and ice climbing, shorthand systems, the systematics of nomenclature, the construction and dissection of regular polyhedra and other geometrical problems [6]. A most useful classification of scientific procedures was developed [5] through the characterizations of dimensionless morphology, phenomenological morphology and absolute morphology. Also, the system of multi-language teaching which will be discussed in another report to this symposium was in part developed with the aid of the method of the morphological box.

Historically, the first large scale task which has been solved with the method of the morphological box is that of the totality of all possible propulsive power plants which can be activated by chemical energy.
In 1939 some of my colleagues of the California Institute of Technology in Pasadena, California, under the direction of Professor Th. von Kármán and Drs. F. Malina and M. Summerfield, with the support of the US Air Force established the Guggenheim Aeronautics Laboratory of the California Institute of Technology (GALCIT), now called the Jet Propulsion Laboratory (JPL), where they occupied themselves with the problem of jet assisted take off rockets (JATOS) for airplanes.
The Aerojet Engineering Corporation (now Aerojet-General Corporation) was subsequently charged in 1942 with the production of the solid and liquid propellant rockets which had been developed at GALCIT. The engineers, however, found it difficult to scale up the GALCIT models.

As director of research of the Aerojet Company I therefore started a comprehensive study of all possible jet engines which can be activated by chemical energy and I explored their various characteristics in terms of the following six parameters P_z.

P_1 = The medium through which the jet engine moves. Four components P_{11}, P_{12}, P_{13} and P_{14} were chosen to designate vacuum, the atmosphere, large bodies of water and the interior of the solid surface strata of the Earth.

P_2 = The type of motion of the propellant relative to the jet engine. P_{21} , P_{22}, P_{23}, P_{24} thus designate rest, translatory, oscillatory and rotatory motion.

P_3 = Physical state of the propellant. This parameter has three components P_{31} = gaseous, P_{32} = liquid, P_{33} = solid.

P_4 = Type of thrust augmentation. P_{41} = None, P_{42} = internal, P_{43} = external.

P_5 = Type of ignition. P_{51} = self igniting, P_{52} = external ignition.

P_6 = Sequence of operations. P_{61} = continuous, P_{62} = intermittent.

Any of the 576 symbolic chains (P_{1i}, P_{2j}, P_{3k}, P_{4l}, P_{5m}, P_{6n}) where i and k can assume the values 1 to 4, j and l the values 1 to 3 and m, n the values 1 and 2 represent a possible propulsive power plant which can be activated by chemical propellants [3].

At the time of my study only five of these, namely the solid and liquid propellant rockets, the aeroduct (ramjet), the reciprocating engine-propellar combination and the Campini piston engine-jet were known. The morphological review had therefore revealed the possibility of an additional 571 propulsive power plants which had apparently escaped the attention of the professional engineers. Unknown to us, however, the British and Germans were working on the aeroturbojet and Schmidt in Munich on the aeroresonator (buzz bomb engine).

With hundreds of new jet engines in view it was obviously not possible to carry out step number four of our

program with the aid of any conventional procedure. With regard to the evaluation of the propulsive efficiency, another pleasant surprise was in store for us which is characteristic of the morphological approach.
Under neglect of irrelevant details and complications it proved possible to derive a good approximation for the specific impulse of any jet engine by using only first principles of mechanics and of thermodynamics. I proposed to call the resulting expression the universal thrust formula [3]

$$I_{sp} = U_e/g = U_o/ [\ -1+(1- \ +2\,\Delta /U_o^2)^{1/2}] \qquad (2)$$

where U_o is the velocity of the missile with respect to the surrounding medium, Δ is the chemical energy available per gram of fuel (hydrofuel, terrafuel) and $= M_f/(M_f+M_m)$, where M_f and M_m are the mass flows per second of fuel and external medium (air, water, earth) through the exhausts of the propulsive power plant.

From 1943 on we proceeded at Aerojet to build as many as possible of the newly invented engines. Some of them proved right away to be surprisingly successful. Many, however, for instance the hydropulse and the hydroturbojet will only come into widespread use when cheap and efficient hydrofuels, that is water reactive chemicals such as $Al(BH_4)_3$ become available (or once they are combined with nuclear reactors).

In order to implement the knowledge gained from the morphological box of the propulsive power plants we therefore had to initiate a systematic study of all possible stable and pseudostable chemicals. This led to the introduction of many new chemicals and opened up the very promising fields of *fragment chemistry* and of *metachemistry* [3].

The study of morphological boxes also suggests the introduction of systems of *nomenclature* which at the present time is in such a state of confusion that much time is being wasted by librarians, engineers and scientists in locating needed information.
The box of the jet engines suggests for instance that one should designate all devices moving through the air, water or the Earth respectively by the prefixes aero, hydro and terra; thus: aeroresonator, aeropulse, aeroturbojet, aeropistonjet and hydroresonator, hydropulse, hydroturbojet, hydropistonjet, and terraresonator, terrapulse, terraturbojet, terrapistonjet.

In expansion of the studies on possible propulsive power plants and propellants we started at the end of World War II work on various vast projects of space research. The first one among these was an attempt on December 17, 1946 at the White Sands Proving Grounds to fire artificial meteors from shaped charges mounted on a V-2 rocket [3] [7]. The first man-made objects (slugs of fused TiC and Al_2O_3) were subsequently successfully fired into interplanetary space and free of the gravitational pull of the Earth from an Aerobee rocket which was launched at Alamogordo, New Mexico, on the night of October 16, 1957. These may now appear to be modest efforts when compared with later spectacular achievements, but they nevertheless remain the *first practical attempts to start the* SPACE AGE [3].

2. The Method of the Systematic Field Coverage

If we start from given pegs of knowledge and infiltrate the surrounding fields until we arrive at other known pegs, we may expect to make discoveries and prove at the same time that nothing has been overlooked. This is really the procedure used by a good detective in tracking down criminals.
During the past thirty-five years I have applied this method successfully in the *search for new cosmic objects and phenomena*.

The main guiding principles which I used are the following:

) All objects may be expected to form *families* whose members exhibit continuous sequences of characteristics. If some types appear to be missing, they most likely are short-lived objects, but it must nevertheless be possible to find them.
If, however, some objects are *really nonexistent*, such as for instance, *stable and electrically neutral nuclei*, or *clusters of clusters of galaxies* this must be due to some very fundamental reasons.

) If the general principles of statistical mechanics are applicable to the large scale distribution of cosmic matter we must expect much of this matter in resting places and configurations which are long lived, that is in *very compact and in very dispersed states*.
Actually there is a close connection between these two inasmuch as during the formation of compact bodies energy must be liberated in the form of electromagnetic and gravitational waves, corpuscular radiation such as the cosmic rays and through the ejection of various types of material bodies.

) Compact bodies may be *formed both slowly or rapidly* (implosively) , the terms slow and fast being defined by the statement in the following paragraph.

) When we talk about the evolution or the *history of a system* (or of the world) we mean that certain pure numbers, which are dimensionless ratios of significant physical parameters of the system change their values as functions of t/ , where t is the time and is a characteristic time within the original system.

) For any large scale search to be effective, the proper *instruments* must be available. For my purposes I promoted the construction of the 18-inch and the 8-inch Schmidt telescopes on Palomar Mountain, which were followed thirteen years later with the installation of the 48-inch Schmidt.
In addition I composed mechanically the *first full size mosaic echelette transmission grating* [3] for the 18-inch Schmidt telescope with the aid of 5 inch x 7 inch replicas kindly sent me by Professor R. W. Wood who later on constructed three additional and more perfect objective gratings.
Unfortunately no full size prism or grating has ever been built for the 48-inch Schmidt telescope, a neglect which almost certainly deprived us of the early discovery of objects like 3C 273 and of a much more effective search for flare stars, supernovae and compact galaxies of all types (BCO = BSO = blue compact extragalactic objects, RCO = RSO = red compact extragalactic objects; ECO = emission-line compact objects, etc.)

The discoveries [5] which I succeeded in making as a consequence of the program of the morphological field coverage for new cosmic objects include among others the first dwarf, pygmy and gnome galaxies, the first compact galaxies of all types, including the BCO, (which are called BSO or blue stellar objects by some) and the more numerous red and infrared RCO (RSO) and ICO (ISO), many groups of compact galaxies, as well as the apparently rare large *clusters of compact galaxies*.
I could also show that intergalactic matter, the existence of which had been vehemently denied by E. P. Hubble, W. Baade and other experts in the field [3] is distributed throughout all of cosmic space between the common galaxies and that this matter consists of stars, dust, gases and plasmas of protons and electrons, in addition to the cosmic rays.
New classes of galactic objects such as the Humason-Zwicky stars, pygmy stars and certain variables were also discovered.

Some of the hypothetical cosmic bodies whose existence I predicted theoretically on the basis of principles developed by the method of the systematic field coverage, however, still remain to be discovered or identified.
These include the neutron stars [8[, the nuclear goblins [9], the neutron star studded gaseous compact

galaxies [10], the pure cosmic balls of light [11] [12] and the neutron star studded cosmic balls of light. These ultracompact objects which contain mostly neutron stars and either gases or trapped radiation are in my opinion the most likely candidates for models of the quasistellar radio sources and certain blue, red and infrared radioquiescent compact galaxies whose large redshifts are probably explainable as Einstein gravitational shifts.

3. The Method of Negation and Construction

This method is based on the principle of the flexibility of truth as I formulated it some thirty-five years ago [13]. In particular, any communicable statement, which of necessity must be formulated in finite terms cannot be absolute. Thus, for instance, the uncertainty principle in quantum mechanics cannot really represent an *ultimate truth because its claim that products* of the uncertainties in the simultaneous determination of coordinates and momenta, or of energies and life times *can never* be smaller than Planck's constant h is too inflexible.
I predict that a determined effort to negate the *absolute certainty expressed by the uncertainty principle* [3], followed by the formulation of a law which is in better accord with the principle of the flexibility of scientific truth will lead to new fundamental insights in theoretical physics.

The method of negation and construction is also most helpful in many rather prosaic circumstances of daily life and it can be particularly useful in breaking down prejudices and beliefs which so often impede scientific and technological progress. As an example among hundreds I mention the problem of the photographic plate whose quantum efficiency in recording optical images is miserably low inasmuch as it takes a thousand light quanta or more to produce one chemically developable grain of silver bromide for instance. It seems that most scientists have tacitly accepted this as a fact about which nothing can be done.
No morphologist, however, will agree to any such defeatist conclusion without being shown an unambiguous proof of its validity. Actually, however, such a proof cannot be given at all and the possibility of recording each individual light quantum photographically remains a certainty. Once one has adopted this attitude many solutions suggest themselves. One of the most obvious consists in the idea of dispersing colloidal droplets of an explosive, for instance, properly colored and doped nitromethane (Jet-X) throughout the emulsion. Every quantum of light will then initiate a microscopic explosion and thus release many times its own energy which can be used for the production of photographic images.

4. The Method of the Extremes

Truth can at best be approximate and "osculate" reality closely only in certain limited ranges of parameters, just as a tangent or a circle of curvature osculate a general curve only in the neighborhood of some chosen point. At far away points departures of the curve from the tangent or the circle become obvious. To discover deviations from any apparently absolute truth we must therefore consider extreme sets of circumstances.

For instance, we may ask if Newton's law holds at distances which are either very small or very large compared with those for which we have tested it. As a result of this inquiry I found that there are no clusters of rich clusters of galaxies [5].
The most direct interpretation of this fact leads to the conclusion that the gravitational attraction between bodies which are separated by more than fifty million parsecs decreases more rapidly than Newton's law would indicate. Likewise, Euclidian space may be a good approximation for those limited regions within which we usually operate but it probably does not represent real space any more if we deal with nuclear dimensions or the universe as a whole.

5. Confrontation of Perfection and Imperfection

Although the morphological approach generally aims at perfection it also is determined not to neglect anything. In this spirit it is interested in the evaluation of all imperfections. This outlook leads often to surprising results.
Thus, a telescope whose image formation of celestial objects is badly affected by chromatic errors, cross diffraction patterns, and multiple reflection ghosts is generally considered a partial failure.
On closer scrutiny it may be found that the mentioned defects are useful and sometimes even necessary for ascertaining the reality of objects , for the discovery of stars of certain colors, for the calibration of apparent magnitudes, for the simultaneous determination of the luminosities of bright and of faint objects, for the distinction of stars and compact galaxies and many other problems.

As to the value of shortcomings in daily life we only need to remember that many a married couple has broken up because of what seemed to be perfection in the character or the behavior of one of the partners becoming unbearable to the other.

A morphological study of the characteristics and the possible values of imperfections of physical objects and devices, of various types of phenomena and of certain ideas, concepts and procedures is under consideration by some of the members of the Society of Morphological Research.

6. The Method of Generalization

Generalization is one of the most useful procedures practiced by the morphological approach. It helps us to achieve broad vistas and to derive solutions of specific problems more easily by starting from more general ones. What is most important, however, is that bold generalization enormously stimulates the imagination and often yields unexpected results.
The idea of simultaneous multilanguage instruction, which I shall discuss in a next chapter is a case in point. Here I restrict myself to a brief sketch of one important issue for the future of man and his society.

It is generally assumed that there are only relatively few men and women of *genius*. As soon as one starts pondering this statement seriously he finds that it is difficult to say exactly where genius starts and ends. In way of a vast generalization I therefore became interested to evaluate the merits of the universal proposition that EVERYONE IS A GENIUS [5] [6], which I intend to expound soon in a book of the same title.
Be it said here only that I consider it as the most important task for morphological research to explore this issue thoroughly with a view to reshaping all of our sterile ideas about education and the construction of a harmonious human society.

D. The Choice of Tasks

Life confronts us with many problems which we cannot disregard. The morphological approach promises to be helpful in solving any of them. Even if we are successful in dealing with these unavoidable problems, however, the question remains as to what our destiny really is and *what ultimate values we should strive for*.
In order to make the correct choice of the goals which one should try to achieve he must first recognize what his genius really is and he must also clearly know what all of the possible human values and valuations really are.
One of the major tasks of morphological research therefore is to establish the morphological box of all human values and to recognize their various characteristics. Everyone who has been lucky enough to realize his very particular genius can then choose from this box those tasks to whose solutions his genius can contribute most.

If I were asked as to what I personally have in mind I should say that I am most interested in the *elimination of all human aberrations*. On the way to the realization of a sound and harmonious human society, however, all men and women will have to make their own unique contributions, and nobody else will be able to take their place if each one puts his very own genius to work.

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