Alexander Gurwitsch And the Concept Of the Biological Field,

Part 1

by Michael Lipkind

Alexander Gavrilovich Gurwitsch (1874-1954)

A student of the great biologist discusses the importance of Gurwitsch's thought and his work.

A great deal could be said about the remarkable life of Alexander G. Gurwitsch, spanning the juncture of two centuries and nourished by two great sources of culture: specifically Russian (he was born and brought up in Russia and spent most of his life there), on the one hand, and Western European, particularly German, on the other (he studied, graduated and began his scientific activity in Munich and continued his work in Strasbourg and Bern). Much could be said about his brilliant intellectual power: By the cast of his mind he was a typical theoretician possessing a rare combination of deep philosophical intuition, with an incredible gift of experimental inventiveness. He comprehensively analyzed all facts and phenomena in an intrinsically vitalistic manner—vitalistic not in an agnostic sense, but in a working sense of this notion. He had a deep devotion to scientific and humanistic principles, together with a tolerance of opposite views, and kindness to all those he met.

An example of his crystalline adherence to principles was his resignation in 1948 from the post of the Director of the Institute of Experimental Biology in Moscow, as a protest against the Lysenko dictatorship in Soviet biological sciences. At that time, this was an act fraught with mortal danger which, fortunately, only made him fall into disfavor until the end of his days.

A peculiarity associated with his works is the quaint fate of some of his findings and ideas which have become a sort of "scientific folklore" when the authorship at times is forgotten.

However, this panegyric can be considered the personal emotional feeling of one who was lucky in his adolescence to become acquainted with Gurwitsch, and to hear from him about the innermost mainsprings of living processes. Some facts about his life should be added.

Alexander Gavrilovich Gurwitsch was born in September 1874, in Poltava, Ukraine, into an educated Jewish family. In his youth, he displayed an inclination to music and painting, and after finishing gymnasium in 1892, he moved to Munich to join the Munich Academy of Fine Arts. He failed the examinations, and instead entered the Medical Faculty of the University of Munich. Very quickly he became keen on the biological sciences, and from the third year started his scientific activity in the laboratory of Professor Karl von Kupffer, a distinguished anatomist and morphologist. Gurwitsch's first work, concerning the influence of the chemical composition of the medium on amphibian development, was published in 1895. In 1897 he graduated from the University of Munich and continued working in Kupffer's laboratory until he obtained a position in the Department of Anatomy of the University of Strasbourg. Here, and later in the Department of Anatomy of the University of Bern (1901-1905) he worked in the fields of embryology, histology and cytology.

In 1903, Gurwitsch married Lydia D. Felicina, who was a Russian student at the University of Bern Medical Faculty, and who subsequently did her doctoral thesis under his supervision. Apart from the great general influence of her personality on the scientific creativity, and the whole life of Gurwitsch, she became an unfailing collaborator of her husband, and co-author of many of his works on mitogenetic radiation.

In 1905 the couple returned to Russia, and soon after, Alexander became professor of anatomy and histology at Bestuzhev High Women's Courses in St. Petersburg. His work there continued until the October Revolution and Civil War of 1917. The St. Petersburg period was one in which his general conceptual view of biological problems was substantially formed. He began there as a highly erudite biologist with an excellent background in physics and mathematics—rare among biologists, especially at that time. During this period his inherent inclination toward understanding the whole enigma of the essence of the living state became focussed on two main

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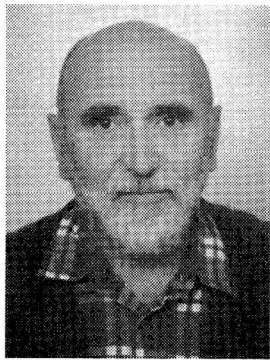
Michael Lipkind was born in Moscow in 1934, and was personally acquainted with Alexander Gurwitsch in his youth. Gurwitsch's brilliant intellectual power, original scientific and philosophical vision, humane personality, steadfast honesty and generosity during a cruel period of Russian history, strongly influenced Lipkind, who considers himself as Gurwitsch's disciple. In 1952, Lipkind attempted to join the Biological Faculty of Moscow University, which was hopeless for a Jew at that time. Then, as a student at the Moscow Medical Institute, Lipkind worked in Gurwitsch's Laboratory of Mitogenetic Radiation, and attended a private course of lectures given by Gurwitsch in his apartment, in the last year of his life. There were only three listeners: Anna Gurwitsch (his daughter), Lev Beloussov (his grandson), and Lipkind.

In 1958, Lipkind graduated from the Moscow Medical Institute but was not allowed to work in Gurwitsch's laboratory. Instead, he was sent to Siberia for three years, to work as a medical doctor. Without the possibility of working in the Laboratory of Mitogenetic Radiation, Lipkind subsequently joined the Institute of Virology, and pursued a career in the field of general and molecular virology. In 1974, he emigrated to Israel, where in addition to his "official" work, he returned to his "old flame," biophysics.

Lipkind is currently a research professor of virology at the Kimron Veterinary Institute, in the Volcani Center for Research in Agriculture, in Beit Dagan, Israel. Since 1987, he has been a member of the Board of Directors of the International Institute of Biophysics (Neuss, Germany), whose main research focus is biophotonics, which is a continuation of Gurwitsch's mitogenetic radiation.

Lipkind's scientific interests range from virology and cell biology to biophotonics and the theory of the biological field. This theory—the topic of this article—Lipkind considers an unprecedented attempt to formulate a non-tautological vitalistic principle. The theory has the form of a mathematical model based on strictly defined postulates that are deeply rooted in biology. Consequently, it has the potential to become a powerful tool that would work when applied to all three levels of biological organization: molecular, cellular, and organismal.

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problems: the regularities of formative processes in embryonic development, on the one hand, and the "miraculous phenomenon of karyokinesis" (mitosis, in his expression), and its initiation factors, on the other. The way to understand the former problem was based on constructing some "supraprinciples" intended to explain various processes occurring in a living system and displayed at different levels of its organization. Precisely during this period, the notion of "field" used in physics was applied by Gurwitsch for the first time for the analysis of morphogenic phenomena.

In St. Petersburg, Gurwitsch was one of the initiators and active members of the "Circle of Small Biologists," which emphasized the conservative arrogance and stagnation of the established universities' "Big Shots."

In autumn 1918, Gurwitsch and his family moved to Simferopol, Crimea, where he headed the Histology Department of the newly founded Tavria University until the end of 1924 (where he became a friend of the famous geochemist Vladimir Vernadsky). The Crimean period was one of the most fruitful in his life. In conditions of practical isolation from the Western world during 1918-1921, he concentrated on two main topics: the further development of the concept of the morphogenic field and its application in various embryological models, and a dualistic conception of the initiation of mitosis. The latter led Gurwitsch to the discovery of mitogenetic radiation in 1923, which brought him a worldwide reputation.

In 1924, Gurwitsch was elected professor of the Department of Histology and Embryology of the Moscow University Medical School, where he worked until 1930. This first Moscow period was marked by intensive studies on the newly discovered phenomenon of mitogenetic radiation, which was widely recognized in the Soviet Union and in the West. A newly elaborated method of biological detection of mitogenetic radiation, using budding yeast culture, proved to be a powerful tool. He also applied the conception of the morphogenic field to some other embryonal models. This was the period of the establishment of Gurwitsch's school within Soviet biology, which included his old students of the Western and St. Petersburg periods, V.V. Polovtseva and, A.A. Lyubishchev; his students from the Crimean period, S. Salkind and G.M. Frank; and his new Moscow students, M.A. Baron, L. Blyacher, M.A. Vorontsova, V.F. Eremeev, A.P. Potoskaya, N.N. Kannegisser, and V.A. Dorfman. At the end of this period, Gurwitsch's classic work, *Histologischen Grundlagen der Biologie* (Histological Foundations of Biology) was published in Jena in 1930.

In 1927, Gurwitsch was invited to Germany, along with a number of distinguished Soviet scientists, this being his first visit abroad since the October Revolution of 1917. At an official reception in Berlin, Gurwitsch met Albert Einstein. In a short discussion with Einstein, Gurwitsch indicated difficulties in finding energy sources in living systems sufficient for the emission of high-energy ultraviolet photons. Einstein expressed his confidence that, like any factual finding, the study of mitogenetic radiation would reach the point at which a purely physical explanation of its energy sources would be found.

At the end of the 1920s, Gurwitsch came to be seen as a symbol of heretical free-thinking by the university authorities. An inevitable conflict occurred in 1929, and Gurwitsch left Moscow University.

In 1930, Gurwitsch was offered a position at the Research Institute of Experimental Medicine in Leningrad. This was the first research institute in Russia not affiliated with any university. It was established in 1890 on the pattern of the famous Pasteur Institute in Paris, founded only two years before. He was given a laboratory in the newly established Leningrad Institute of Roentgenology and Radiology. For the first time, he was able to plunge into pure research without any teaching obligation.

The Leningrad period was marked by further intensive studies using mitogenetic radiation as a powerful tool for analyzing the molecular substrate of various living systems—plant, animal, and microbial. The application of mitogenetic radiation methods to various biological problems led to the development of essentially new views and conceptions when applied to neurophysiology, biochemistry, and carcinogenesis. At that time, the phenomenon of degradational mitogenetic radiation was found (emitted by dying cells) and became the basis for the concept of "non-equilibrated," unbalanced molecular constellations. This phenomenon underlay the theory of the vectorial biological field.

During the Leningrad period, Anna Gurwitsch, Alexander Gurwitsch's daughter and successor, began working in the field of mitogenetic radiation.

In January 1934, Gurwitsch was invited by the Vienna Biological Society, the Pasteur Institute, and the Holland Student Association, to read a series of lectures on mitogenetic radiation in Vienna, Paris, Amsterdam, Leyden, Utrecht, and Groningen. In the autumn of the same year, he participated in the International Congress on Electroradiobiology in Venice, where he presented a report on "The Contemporary State of the Problem of Mitogenetic Radiation." During these two visits to the West, which turned out to be his last, Gurwitsch became acquainted with the main Western researchers working on mitogenetic radiation.

In autumn 1941, Leningrad was besieged by Nazi troops. In conditions of starvation, Gurwitsch and his family, along with other scientists, were evacuated to Kazan on special planes. Here, in hard wartime conditions, without any possibility for experimental studies, he concentrated fully on purely theoretical work, and here, his field theory acquired its final form under the name of the vectorial biological field. It was published in Russian in 1944, and, after the war, in French in Leyden (1947).

Immediately after the war, Gurwitsch was appointed director of the Institute of Experimental Biology, which was affiliated with the newly established USSR Academy of Medical Sciences. He was the head of the Department of Mitogenesis at the Institute during the same period. The appointment lasted until August 1948. This was a period of intensive experimental studies, especially on the application of mitogenetic radiation analysis to the problems of neuromuscular excitation and carcinogenesis. Gurwitsch was also involved in an experimental analysis of karyokinetic (mitotic) phenomena by means of the postulates of the theory of the vectorial biological field—the work was carried out by L.Ya. Blyacher and E.Ch. Puchalskaya.

During the Leningrad and second Moscow periods, Gurwitsch's scientific school acquired a number of talented researchers and ardent followers: E.S. Billig, L.D. Lyosner, B.S. Pesochensky, E.Ch. Puchalskaya, and N.S. Slavina.

In 1948, the notorious August Session of the Academy of Agricultural Sciences, organized by T.D. Lysenko, took place. This was the beginning of the gloomiest period for the Soviet biological sciences—the period of forced obedience to primitive obscurantist dogmas in all branches of biology. In such a medieval atmosphere, Gurwitsch, unlike most scientists at the time, made the only possible form of protest: He submitted his resignation and retired. At the time, Gurwitsch was 74 years old, and remained full of creative activity. Working at home, he practically directed the laboratory of mitogenesis, which was more and more cut off, until its liquidation in 1953. Although it was re-established soon after, its personnel included only two in tenure track positions, Professor Anna Gurwitsch and Dr. Victor F. Eremeev. However, a number of young volunteers, students, and employees of various institutions worked in the laboratory, which was crammed into one, and later, two rooms.

At that time, most of Gurwitsch's efforts were concentrated on his last work, *Analytical Biology,* which included the main epistemological premises for theoretical biology, and the fullest description of the conceptions of his theory of the vectorial biological field. This book has not yet been published, and still awaits its readers. Only Gurwitsch's close followers have read the manuscript. I myself, by just a lucky chance, had the privilege to be one of a few listeners to the course of lectures which Gurwitsch read at home during 1953-1954, just before his death on July 27, 1954.

The Biological Field Theory:
Prerequisites, Origin and Conceptual Development

Gurwitsch's central theoretical work was the development of the concept of the biological field, which he first introduced into biology as a notion of "field" that had previously belonged to the vocabulary of physics. In his 1912 paper, "Die Vererbung als Verwirklichungsvorgang" (Heredity as a Process of Realization), the notion of field was associated with the conception of the co-subjection of elements to a common morphogenetic factor, as opposed to an alternative conception considering the whole morphogenesis as a result of interactions among the elements. Gurwitsch's field conception underwent successive developments, from the first abstract models describing single morphogenetic phenomena, to the general theory of the vectorial biological field dealing with all the levels of organization of the living organism—morphological, cellular, and molecular.

Historical Background

At the turn of the 20th century, when Gurwitsch started working on the whole problem of ontogenesis, several new developments in biology became key influences on the formation of his biological concepts. The first was the rediscovery of the basic laws of formal genetics discovered by Gregor Mendel in 1864, and the second, the crucial experiments in embryology performed independently by Wilhelm Roux (1850-1924) and Hans Driesch. The studies initiated by Roux led to the establishment of a new branch of developmental biology, the mechanics of development (Entwicklungsmechanik), which flourished, and which culminated in the famous experiments by Hans Spemann and Hilde Mangold (1924). Spemann's experiments resulted in the discovery of "embryonal induction,"

the inductive capacity of a particular part of an embryo transplanted onto another to determine the morphogenic fate of the local tissue surrounding it. The experiments performed by Driesch on harmonic regulation in the embryo, underlay the establishment of a clearly expressed vitalistic conception.

Any theory of development or heredity, no matter how complicated, at that time was based on one of two basic theoretical concepts—preformism or epigenesis—which had dominated the minds of biologists from the very beginning of scientific biology, often serving as "supreme" principles. The roots of preformism can be traced back to Hippocrates, while the idea of epigenesis comes from Aristotle.

According to the logical structure of preformism, the zygote (fertilized egg-cell) contains all the potential prerequisites for the development of a future organism, with all its specific patterns, features, and properties. Evidently, the original concept of preformism considered the whole chain of events constituting the embryo's development to be "predestined" by these potential prerequisites. However, this original, general definition of the principle of preformism gave way to a modified concept based on the idea that all the observed complexity of the organism, can be reduced to separate independent features that can be projected onto strictly determined, separate entities contained in the zygote. These entities are responsible for all the actual species-specific features. Using the contemporary vocabulary, one can define such entities as genes and, accordingly, classic Mendelian genetics can be considered a pure form of this kind of preformism.

As to the classical embryological preformism, the zygote presents a puzzle-like (mosaic) spatial distribution of the entities inside it, with each entity being responsible for a certain morpho-anatomical part of the future organism. Thus, the development of the embryo is just an evolution of these preformed and predetermined entities. Accordingly, there are rigid, unequivocal connections between each such entity and the corresponding part of the embryo: Hence, each ontogenetic stage can be reduced by projection backward, through the chain of all previous stages, to the initial stage which is the zygote itself.

Epigenesis, in its initial form, was just an alternative to preformism. According to its logic, any momentary stage of an embryo's development can be deduced from an immediately earlier stage only, but not from one several steps earlier. Thus, contrary to preformism, no stage of the embryo's development has a direct, unequivocal prerequisite in the zygote: The zygote has the prerequisite only for the first act of the whole development. Similarly, any stage of the whole chain of development contains only an actual prerequisite for the stage immediately following it. These are epigenetic actual prerequisites as opposed to the preformistic potential prerequisites. According to this approach, the developing embryo system presents a combination of partly independent and partly non-rigidly associated processes. If one analyzes the development not in the genealogical, but in the chronological order, at a certain stage something new appears without any visible prerequisite, and it, in turn, is a prerequisite for the next stage.

The doctrine of developmental mechanics was founded by Wilhelm Roux, together with the "causal-analytical" method in embryology (1895), according to which the embryo is compared to a complicated mechanical gadget. In order to under-

stand how this mechanism works, one should know how it is constructed and what part acts on another during development. In other words, one should know the localization of the causes of development. In this respect, the main problem is to know whether the cause of the development of a certain part of the embryo is localized in this very part (self-differentiation), or needs the influence of another part, or from the external environment (induced differentiation). One approach to solving this problem is to change the local environment: to isolate this part, to combine it with another one, or to change the external environment, having in mind to reveal the causal connections.

The general problem of embryology, according to Roux, is the formation of visible heterogeneity from something invisible, the main research task being to reveal the causal connections between these two states: invisible heterogeneity—visible changes. As to the nature of this invisible heterogeneity, whether it is predetermined (preformism) or appears de novo (epigenesis), Roux himself hesitated, while other followers of the causal-analytical method, such as W. His and R. Lancaster, adopted preformism.

In 1887, Roux raised the question of whether the development of two blastomeres depends on each other. He used a frog embryo at the stage of two blastomeres (two cells) and killed one of them with a red-hot needle. The remaining blastomere developed into only half of the embryo, which seemed to support the principle of preformism.

However, Hans Driesch performed a similar type of experiment in 1891, mechanically separating two blastomeres from a sea urchin embryo, which produced a crucial result: From each blastomere, the *whole* embryo developed without any morphological defect. The development of the whole from a part was called by Driesch "embryonal regulation." Afterwards, it was shown that the technical approach used by Roux was not suitable, because the remaining, killed blastomere prevented the other live one from developing properly. Driesch performed other experiments, using various organisms such as Coelenterata, Echinodermata, and Ascidia, which consisted of perturbing various parts of an embryo, as well as mixing some of its parts. His results were similar: formation of a normal embryo after drastic interventions into its normal development. One of the impressive results was the development of a morphologically normal Hydroid embryo, after a single cell was removed at the 32-cell blastomere stage.

Such general phenomena were called by Driesch "harmonic regulation." Driesch's harmonic regulation was demonstrated on the embryo level, that is, after cleavage of the egg. More recent experiments on intracellular manipulation have shown that suction of about one-fourth to one-third of the zygote cytoplasm will be followed by the development of a normal embryo.

Driesch drew important and far-reaching conclusions from his experiments. He suggested two principal notions: equipotentiality and equifinality. The former means that all the elements (cells) of a whole (embryo) are equal in their potential morphogenic capability, each having a full set of possible potencies. The latter means that the final result of the development—formation of a highly specific mature organism—may be reached by quite different paths. Thus, the two notions are the very expression of the epigenetic principle, as opposed to the preformist one: There is no intrinsic predetermination of an element's individual destiny, nor is there a rigid spatial distribution of the prerequisite entities inside the zygote, with exactly scheduled specific roles for each one in development.

These considerations led Driesch to his classic general conclusion: The fate of the element is a function of its location within the whole. The whole was called by Driesch a "harmonic whole," to which he ascribed a teleological property, a factor of realization of the purpose of development. This he called *entelechia* after Aristotle, and defined it as a non-material, non-spatial, metaphysical factor that leads and organizes the development of the embryo, even if its parts are drastically perturbed, mixed, or deleted. Thus, designating *entelechia* as *vis vitalis* (living force), Driesch gave the name "vitalism" to his doctrine (Driesch 1908, 1915) and counterposed it to Roux's causal-analytical method.

Apart from the factual contribution of both schools, the confrontation arose from differing philosophical backgrounds, namely, different definitions of the notion of cause. The vitalistic conception developed by Driesch was based on the notion of the final cause (purpose) (Aristotle's *causa finalis*) while the causal-analytical method of Roux was based on the notion of the immediate (acting) cause. Considering *entelechia* to be unavailable to rational analysis, Driesch himself left experimental science, having discouraged any potential followers from exploring this direction. The causal-analytical school founded by Roux, and highly developed by Spemann (1936), attracted many followers, and has determined the face of contemporary embryology.

Upon this background, the field conception developed by Gurwitsch became an alternative challenge to the principle of preformism underlying the dominant trend of contemporary biology.

Gurwitsch's Critical Analysis Of the Main Theoretical Conceptions in Biology

Gurwitsch's attitude toward the purely descriptive studies in morphology (cytology, histology) of that time was clearly negative, especially when such studies were followed by arbitrary and speculative interpretations, which was very often the case. This reflected his negative view toward studies performed blindly, according to the "let's see what we get" approach. His scheme of research consisted of a comprehensive deductive analysis from all the facts related to the problem, inductive construction of a working hypothesis, and then its experimental examination. Certainly, this is rather a general (perhaps truistic) scheme of a proper scientific analysis, but the history of science shows that the scheme has been carried out only in the really distinguished cases. In Gurwitsch's case, his capacity for deductive analysis was remarkable for its wide scope of included facts related to different fields of biology: Confrontation with these facts led sometimes to unexpected conclusions. Such a wide scope was based on his vitalist philosophical orientation, which permitted him to foresee a common principle in quite different biological phenomena. Correspondingly, the inductive part of Gurwitsch's analysis was intrinsically original and bold. As to the experimental examination of his conceptions, the best example is the discovery of mitogenetic radiation, which, like the discovery of Pluto, was done "at the tip of a pen."

Figure 1
CAUSAL MATRIX OF DISTINGUISHABLE COURSES OF DEVELOPMENT

Schema of the mechanics of development (Entwicklungsmechanik) proposed by Wilhelm Roux (I). Hans Driesch's concept of harmonic regulation is illustrated in the remaining sections. The embryonic material undergoes excision (II), addition (III), and disturbance (IV).

Source: Beloussov 1980

The revived formal genetics, in the original description by Gregor Mendel, highly fascinated Gurwitsch by its logical, almost mathematical strictness. However, very soon he understood that formal genetics, by its definition of the gene, as well as by its "evident" conviction that the whole organism may be resolved in full into Mendelian features, could not logically explain the realization of morphogenesis itself. In his paper, "Heredity As a Process of Realization" (1912), Gurwitsch wrote that embryogenesis itself turned out to be beyond the consideration of Mendelian genetics, which treated the transfer of hereditary features as if it were an isolated process apart from embryogenesis. The point is that the gene, by definition, is characterized by chemical parameters, determining the mechanism of its action. (One should take into account that all these considerations were made when nothing was known about the structure of the gene, although the same logic is relevant for the case of modern genetics based on the universal biochemical code.) Thus, the mechanism of gene action inside the cell logi-

cally is free of contradictions. However, most of the Mendelian features appeared to be collective phenomena involving many cells in their realization.

Gurwitsch gives an example of the Mendelian features of smooth and jagged contours of a nettle leaf. Evidently, the realization of such a feature is the result of specifically directed movements and mitoses of many cells into the corresponding leaf contour, but the gene in each of these cells is not able to guide such actions. The gene "speaks cellular language," while the feature is realized on the supracellular level. Gurwitsch did not see a solution to this contradiction within genetics.

Roux and Driesch had obtained experimental results concerning the separate temporal determination of the anterior-posterior and the dorsal-ventral axes of the developing amphibian limb. Harrison (1918) had done striking related experiments on the transplanted amphibian limb, and Gurwitsch subjected the theories of the two schools of thought, mechanistic and vitalist, to a comprehensive analysis on this question of determining axes in the embryo. This analysis can be well demonstrated with the scheme of a causal matrix (Figure 1) presented in L.V. Beloussov's *Introduction to General Embryology* (1980).

According to Roux's scheme (Figure 1, I) there are some strict causal connections originating from factors localized in the egg (A1, B1, C1, D1), and through intermediate stages 2 and 3, they lead to the respective "final products" projected on a final stage of the matured organism (A4, B4, C4, D4). In addition to these immediate connections, there may be influences (mainly at the initial stages of development) from the external environment (E → A1) as well as unilateral or bilateral influences of different parts of the embryo on each other (B2 → A2; C3→B3). According to this scheme, the development cycle can be completely and unequivocally resolved into separate causal connections, and the aim of analysis was thought to be the deciphering of these connections. This conceptual approach to studying the mechanics of development led to some outstanding achievements, the most prominent being the discovery of the phenomenon of embryonal induction by Hans Spemann.

However, the phenomena of harmonic embryonal regulation discovered by Driesch did not conform to the principle of strict causal connections. Indeed, after extraction of some embryonal material (parts B1, C1, shown removed in Figure 1, II), the final structures B4 and C4 are formed nonetheless, although the mature embryo is correspondingly smaller. In contrast, the addition of redundant material (double portions of B1 and C1, in Figure 1, III) did not lead to doubling of final B4 and C4; and perturbation of the embryonal material did not prevent the development of the final mature embryo (Figure 1, IV). The conclusion was that the embryo's development cannot be resolved fully into a network of separate cause-and-effect connections, but that the embryo as a whole is responsible for the final result.

Thus, Gurwitsch turned away from the preformist causal-analytical conception of developmental mechanics, and adopted the vitalist conception of the whole as a factor organizing the "normal" embryogenesis as well as harmonic regulation. However, while Driesch himself refrained from further research on the whole, which he associated with the agnostic *entelechia*, not available to rational analysis, for Gurwitsch this was just a starting point for the development of his own origi-
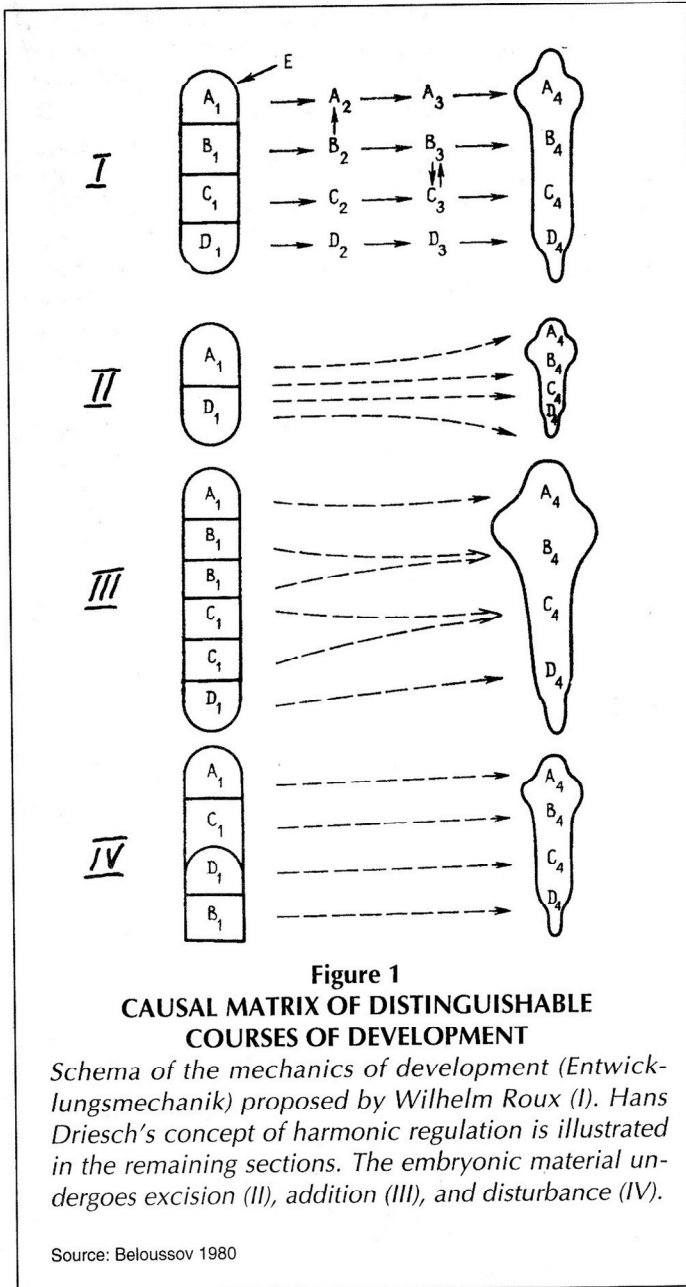
nal path of research. This path considered the whole as an object for scientific analysis, that is, as a "working" principle.

Elaboration of Quantitative (Statistical) Criteria Confirming the Influence of the Whole on Its Elements

Although Driesch's experiments seemed to have substantially shaken the conception of unequivocal causal connections, Gurwitsch considered it necessary to show the applicability of Driesch's conception as a "working principle" for the analysis of a normal development cycle, without drastic experimental interference. In his 1910 paper "Über Determination, Normierung und Zufall in der Ontogenese" (On Determination, Regulation, and Contingency in Ontogenesis), Gurwitsch made a unique analysis of the behavior of elements (cells) during the development of geometrically exact and symmetric forms, such as a sea urchin gastrula, the crystalline lens and cornea of a chick embryo, and an onion root. The question was, whether the exact geometrical, definitive "macroform" of the embryo (or the organs) is associated with (and the result of) the correspondingly strict and coordinated behavior of the elements. The experiment ("Naturexperiment" according to Gurwitsch), consisted in the calculation of the numbers of mitoses in both halves of the macroforms, and the comparison of the empirical curves with the theoretical Gaussian curve of normal distribution.

The results showed different kinds of distributions in the empirical curves. Only in the case of the sea urchin gastrula was the distribution "subnormal," that is, the empirical deviation (difference between the numbers of mitoses in the halves) was less than the standard deviation of the normal (Gaussian) distribution. In the other cases, the empirical distribution of the number of mitoses was either normal or "supranormal." However, there was no case of mirror symmetry between single mitoses synchronously occurring in both halves. The case of the subnormal distribution of mitoses was designated by Gurwitsch as "determination," which means that there is an individual causal interaction between the symmetric mitoses. In the cases of the subnormal distribution of "microprocesses" (mitoses) in the developing macroform, one should accept the presence of immediate causal connections between the microprocesses. In contrast, both normal and supranormal distributions of microprocesses, designated by Gurwitsch as "normating" (from the German *Normierung* [usually translated as standardization or regulation—eds.]) show the absence of the immediate causal connections between the microprocesses. Instead, the microprocesses are subordinated to a "single normating factor," which is common to all. Thus did Gurwitsch establish the principle of the subordination of "equipotential" elements to a common invariant "normating" factor, as an alternative to the principle of immediate causal interactions between specifically "predestined" elements.

The actual influence of the "normating" factor on the elements is associated with their localization within the developing macroform. This notion became a prototype of Gurwitsch's field principle. In his paper "Heredity As a Realization Process" (1912), Gurwitsch suggested criteria for the equipotential elements being under the influence of the whole, which is expressed as a field factor. These criteria are as follows: (a) the dependence of the elements on their location within the whole (their fate, according to Driesch, which
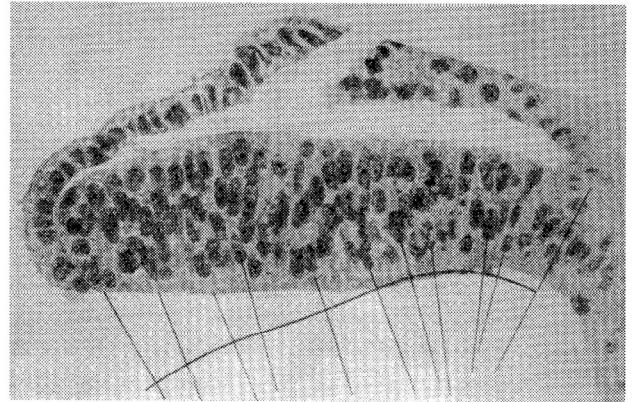

Figure 2
ORIENTATION OF CELL AXES IN THE BRAIN VESICLE OF A SHARK
The orientation of the axes of cell nuclei in the mitotic zone of the shark's brain vesicle has prognostic significance.

Source: A.G. Gurwitsch 1914

can be expressed either by their movement and/or by their differentiation) is fairly certain and mathematically simple; (b) the successive putting in order of the arrangement of the elements during the embryo's development (the whole), from apparent disorderly dispersion to a more and more regular spatial distribution; (c) "the including," the whole (a geometrically regular contour of the macroform shape), is more precise than the "included" (the distribution of the elements constituting this contour at the microlevel). The meaning of this is that the geometrical exactness of the macroshape is not constituted by the exactly shaped and correspondingly arranged "included" elements (like that in puzzle mosaic constructions, where each piece is precisely localized). On the contrary, the whole itself acts as an organizing factor, providing a particular arrangement of the elements whose individual microshapes, not being predetermined, are adapted to (dictated by) the macroshape contour at each geometrically specific point.

Thus, by elaborating criteria of the potential influence of the whole as a factor on the elements' behavior during normal embryogenesis, Gurwitsch for the first time attempted to make the concept of the whole a working concept, and hence, converted it from *entelechia*, which was declared unknowable, to a working principle available to strict scientific analysis.

Construction of Embryonal Morphogenic Fields

According to Gurwitsch's analysis, therefore, the whole subordinates the elements to a single common invariant field factor. Indeed, such a conception makes sense only when the dependence of elements on the field is invariant within a sufficiently lengthy period of the embryo's development.

In his paper, "The Mechanism of Form Inheritance" (1914), Gurwitsch suggested an invariant law explaining the movements of embryonal cells over a long period of development. The work was based on a histo-embryological study of the movements of epithelial cells of the developing shark brain. It
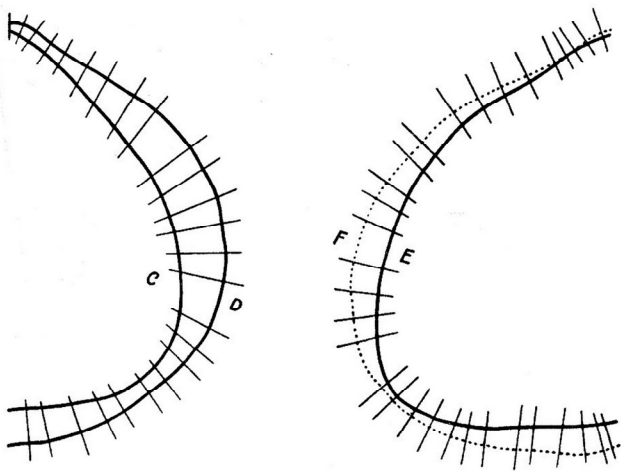
Figure 3
THEORETICAL CONSTRUCTION COMPARED WITH THE OBSERVED FORM OF THE BRAIN VESICLE
Agreement of the predicted (E→F) with the observed (C→D).
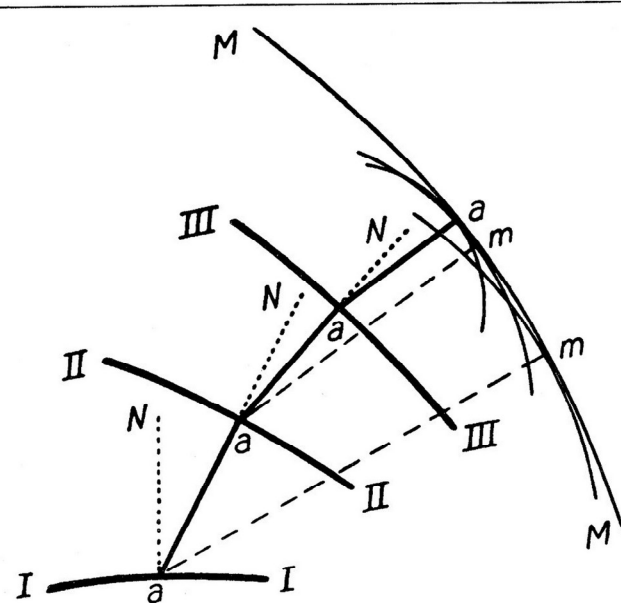
Source: A.G. Gurwitsch 1914

Figure 4
TRAJECTORY OF AN EPITHELIAL CELL (NUCLEUS) UNDER THE INFLUENCE OF THE DYNAMICALLY PREFORMED MORPHA
During the morphogenic process, the moving cells are oriented as if attracted by a "surface of force," designated by Gurwitsch as a "dynamically preformed morpha" (DPM). Contours of successive stages in the development of an epithelial layer are shown in I, II, and III, with N representing perpendiculars to the momentary surface of the layer, am the shortest distance from the base of the perpendiculars to the DPM surface, and aaaa the actual cell (nucleus) trajectory, the bisector between N and am.

Source: A.G. Gurwitsch 1914

was the first embryological study in which the movement of the epithelial cells within the neural layer was found. The crucial discovery was that at each moment of the development of the embryo's cerebral vesicle, the long axes of cells in the internal layer of the neural epithelium were not oriented perpendicularly to the layer surface, but at an angle of 15 to 20 degrees. Such orientation turned out to have a prognostic significance: A curve constructed normal to the cell axes at a certain developmental stage, will coincide with the actual shape of the cerebral vesicle at a later stage of development (Figures 2, 3, 4). Gurwitsch compares such a prognostic orientation with the turning of a ship's helm which precedes the turning of the ship itself.

On the basis of these data, Gurwitsch formulated the following abstract invariant regulation. During the morphogenic process, the moving cells are oriented as if they are attracted by a "surface of force" which was designated by Gurwitsch as "dynamically preformed morpha" (DPM). According to this concept, at each moment, the cells' long axes are oriented along the bisector between a perpendicular to the actual surface of the developing layer, and that of the DPM (Figure 4). If, in the limits of this construction, one analyzed a set of the successive shapes of the developing layer, one could see that some points of the layer are at a minimal distance from the DPM surface, while others are at a maximal distance (Figure 5). According to the DPM conception, the cells in the former area are under a stronger attracting influence of the DPM than the latter. Correspondingly, the actual microscopic picture shows strong polarization of the cell nuclei in the areas close to the DPM surface, and their disorderly arrangement in areas remote from the DPM surface. This polarization is measured by calculating the degree of dispersion of the orientation of cell axes around some mean position (perpendicular to the layer) in both areas (Figure 6), and in some cases strong polarization (intensive attraction by the DPM) and dispersion are evident without special calculations (Figure 7).

Thus, the "invariant law" describing the behavior (movements) of the cells during a relatively long period of development was demonstrated. However, the law was based on only one specific object, its mathematical expression was too complicated and close to a simple interpolation, and its teleological inclination was evident, because the law's action was associated with the DPM, which did not exist at the moment of its action.

Gurwitsch elaborated on the field principle in his next paper, "A Concept of Embryonal Fields" (1922). Logically similar invariant constructions were made for the case of the morphogenesis of the floscule of the chamomile plant (Matricaria chamomilla), and the hats (fruit bodies) of two mushroom species.

The mature form of the chamomile floscule has the geometrically regular shape of a stereometric paraboloid. However, at earlier stages, the developing floscule shape is not so regular, and only gradually reaches the definitive paraboloid form which can be considered a kind of "dynamically preformed morpha." The behavior of the components of the regular paraboloid, which are single flowers consisting of proximal receptacles and distal corollas, is quite remarkable. Evidently, the lower flowers of the floscule ("the included") must grow faster in order to allow the formation of the regular

paraboloid shape of the floscule as a whole ("the including"). The growth of each single flower results from the growth of the parts of both its corolla and receptacle. It was found that the accretions to each part are not strictly determined, and can be quite different, but that they are coordinated in such a way that the resulting growth velocity of the flower as a whole is strictly regular, securing the paraboloid shape. Some individual variations in the flower's growth velocity lead to compensatory bending of the flower's axes, and the stretch-ing of their parts (Figure 8, 5a, 5b). Gurwitsch's invariant law is expressed by the DPM paraboloid force surface, now designated a "field," which attracts the elements (single flowers) along radial trajectories so that the direction and accretion values of each individual flower are the function of its localization in the field.
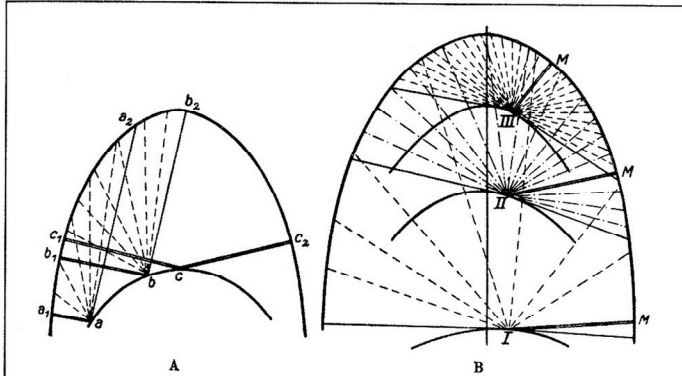
Figure 5
INFLUENCE OF THE DPM ON VARIOUS POINTS OF THE SURFACE LAYER

The initial stage of development is shown in A, and the following phases, I, II, and III, are shown in B. Various points on the surface of the epithelial layer are designated a, b, and c. Various points on the DPM surface are identified as a1, b1, c1, a2, b2, and c2. The direction of maximal influence of the DPM is indicated at each stage by M.

In the initial stage, point a has one predominant M direction (a→a1), while c shows two opposed M directions (c→c1 and c→c2). In the following stages, I→II→III, the observed point eventually comes under a single M influence: the distance III→M is significantly shorter than any other radial line from III.
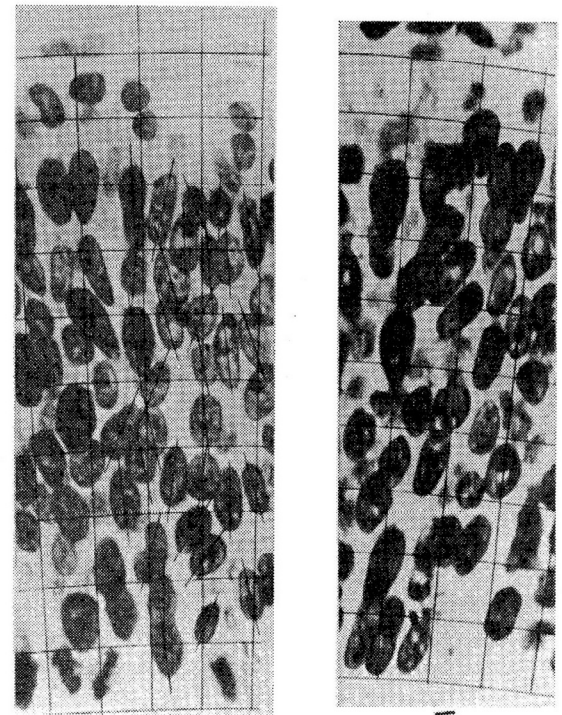
Source: A.G. Gurwitsch 1914

Figure 6
**DISPERSION OF CELL AXIS ORIENTATIONS IN THE EPITHELIAL LAYER OF THE BRAIN VESICLE**

Image I shows an area distant from the DPM surface and displays maximal dispersion of the axes of the cell nuclei from lines normal to the surface of the layer. Near the DPM (Image II), the dispersion is minimal.

Source: A.G. Gurwitsch 1914

Figure 7
POLARIZATION AND DISPERSION OF CELL AXES AS A FUNCTION OF INFLUENCE OF THE DPM

Images I and II show two regions of the epithelial layer that differ in their distance from the DPM surface and correspond to the different coordinates in Figure 5. Image I corresponds to point a (Figure 5A—minimal distance from the DPM in the direction a→a1). The polarization and slanting arrangement of the cell nucleus axes, oriented in the M direction (maximal influence of the DPM), is clearly recognizable. Image II corresponds to point c (Figure 5A—equal distance of the point from the opposite sides of the DPM surface c→c1→c2) and shows a maximal dispersion of axes.

Source: A.G. Gurwitsch 1914
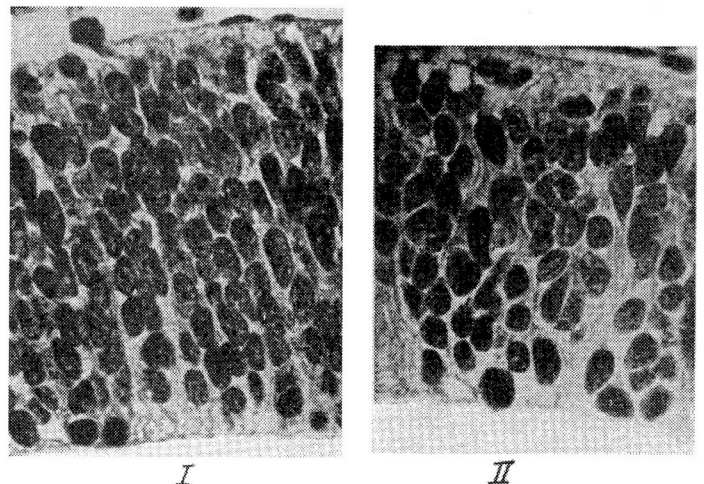
The morphogenesis of two kinds of mushroom is described by another kind of field structure. At the early stage, the developing fruit body of a gymnocarpus mushroom (Marasmius sp.) consists of a disorderly bundle of hyphae whose edges define the correspondingly loose and indefinite contours of the body. As it develops, the edges of the hyphae are "brushed up" and, accordingly, the contours become more geometrically regular (Figure 9).

In the case of an angiocarpus mushroom, the developing fruit body at the early stage also consists of a disorderly plexus of hyphae. As it develops, a geometrically regular arched line looms, located not upon the upper edges of the hyphae, as in the case of the Marasmius, but below the edges of the hyphae. The next developmental step displays loosening, and finally, falling off of the edges of the hyphae that are above the contour to be formed (Figure 10).

The morphogenic field in this case is described by the following structure: If the plane projection of the mushroom's hat shape is considered, there are two point field sources located at the edges of the definitive form of the hat body (Figure 11). These are the sources of forces, whether attractive or repulsive, which decrease in proportion to distance and are summed up according to the parallelogram rules of force composition. Hence, a set of equipotential surfaces can be obtained, one of them corresponding to the major value of the vertical force component (Figure 11, dotted line). This arched line corresponds to the distal surface of the Marasmius mushroom hat, along which the edges of the hyphae are "brushed up." It also corresponds to the barrier line above which the edges of the hyphae fall away in the angiocarpus mushroom. This field construction is quite different from the concept of the DPM used in the case of the shark brain vesicles and the chamomile floscule morphogenesis, because now the definitive forms of the mushrooms' hats do not correspond to DPM attracting-force surfaces, but are the equipotential field surfaces originating from point sources. Another important aspect is that this kind of field does not have the teleological coloration of the previous DPM constructions and can be considered a causal factor.

The next important step in the construction of the morphogenic field was made by A.W. Anikin, in studies under the direct guidance of Gurwitsch (A.W. Anikin 1929). These stud-
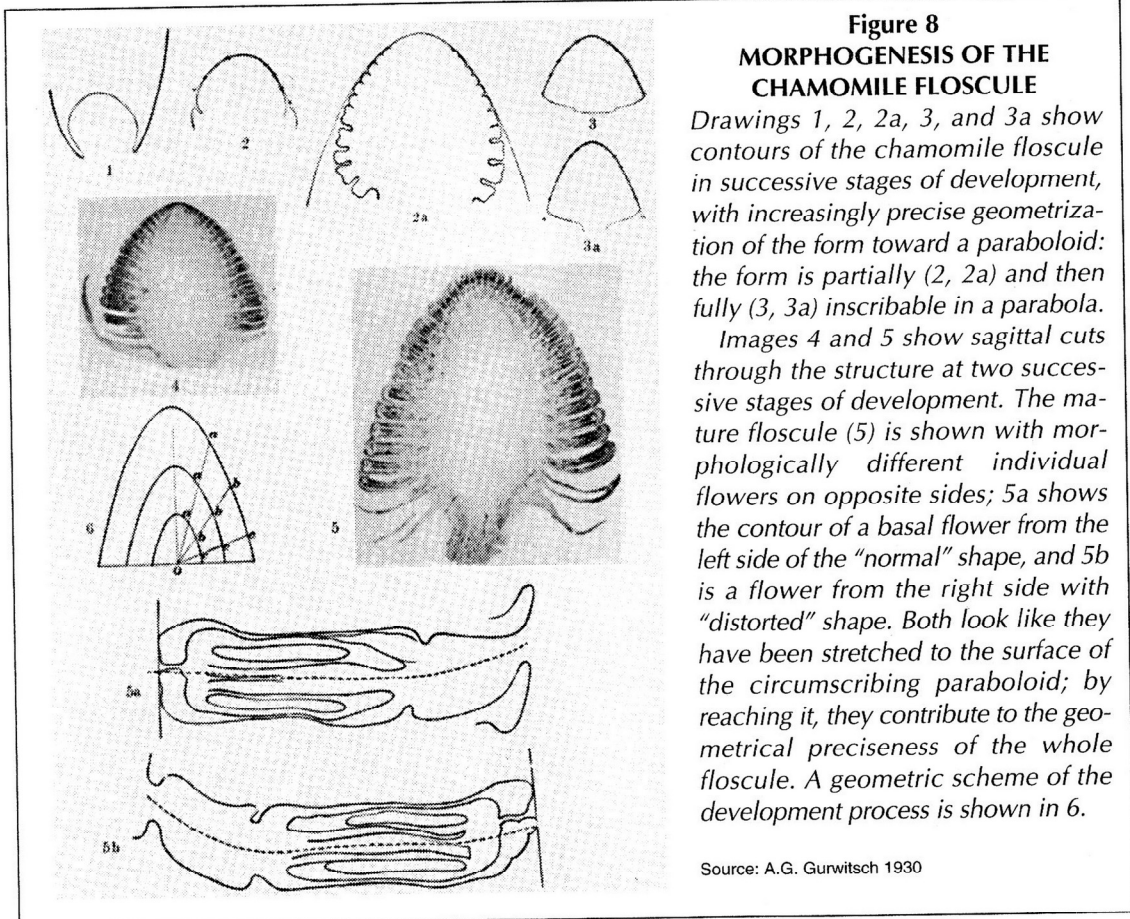

Figure 8
MORPHOGENESIS OF THE CHAMOMILE FLOSCULE

Drawings 1, 2, 2a, 3, and 3a show contours of the chamomile floscule in successive stages of development, with increasingly precise geometrization of the form toward a paraboloid: the form is partially (2, 2a) and then fully (3, 3a) inscribable in a parabola.

Images 4 and 5 show sagittal cuts through the structure at two successive stages of development. The mature floscule (5) is shown with morphologically different individual flowers on opposite sides; 5a shows the contour of a basal flower from the left side of the "normal" shape, and 5b is a flower from the right side with "distorted" shape. Both look like they have been stretched to the surface of the circumscribing paraboloid; by reaching it, they contribute to the geometrical preciseness of the whole floscule. A geometric scheme of the development process is shown in 6.

Source: A.G. Gurwitsch 1930

Figure 9
MORPHOGENESIS OF THE GYMNOCARPUS MUSHROOM

Successive stages of development are shown in 1, 3, and 4, while 2 is a schematic of the arrangement of the fungal threads (hyphae). The gross morphology of the mushroom is shown in 4a.

Source: A.G. Gurwitsch 1930
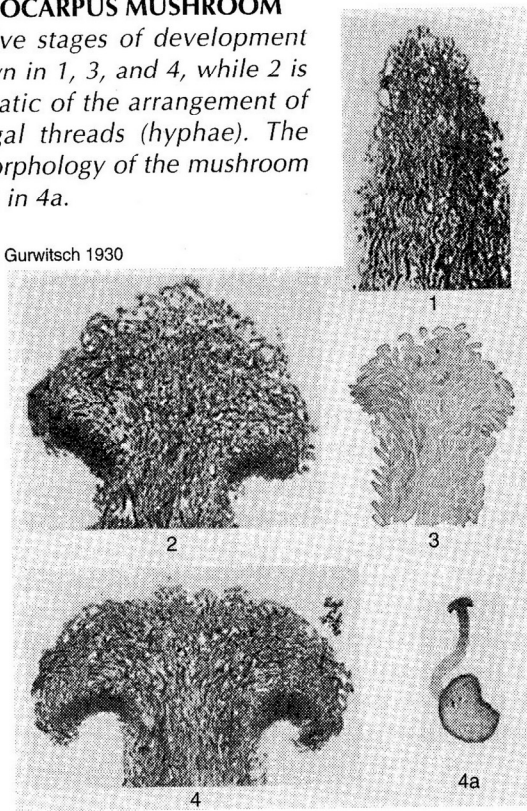
ies were an analysis of changes in the shape of nuclei of mesenchymal cells during the development of the triton phalanx cartilage. In the transverse section of the phalanx, various shapes of the nuclei are distributed with a certain regularity. In the center of the section, the nuclei are of round shape, which changes to an increasingly curved one (bean shape), depending on distance from the center. However, beyond a certain critical distance toward the periphery, the shape again becomes round. The range of forms of the nucleus can be described by a law which is a function of location relative to the phalanx axis of symmetry. The law is based on the idea that the geometrical center of the section transverse to the axis, is a point source of a repulsive isotropic field, acting on each point of the surface of the nucleus. Insofar as mitoses occur mainly along the axis, and the nuclei move centrifugally, the momentary velocity (v) of each point of the nucleus is inversely proportional to the distance of the point from the source, and can be expressed by the differential equation:

$$\mathrm{d}\,R = \frac{K}{\mathrm{d}T} = \frac{V}{R}\,,$$

where R is, in general, coordinates of the given point and, in particular, the point's distance from the field source; t is time, and K is a coefficient of proportionality. Integration of this equation gives an expression combining the distance traversed by the point and the time of travel. If the initial distance between the point and field source is R, and the point moves for an additional segment r in the centrifugal direction, this will take time t', which is associated with R and r by:

$$2Kt = r^2 + 2Rr.$$

On the basis of this equation, a graph can be constructed of the dependence of the velocity of each point of the nucleus surface on its distance from the center, and hence it is possible to infer and construct theoretical shapes of the nuclei, as a function of their distance from the point source of the field (Figure 12). These theoretical shapes are highly similar to the actual morphological appearance of the nuclei in histological preparations (Figure 13). The deduced formula of postulated field action describes very well the observed phenomenon in the morphogenesis of the triton phalanx. There is a remarkable
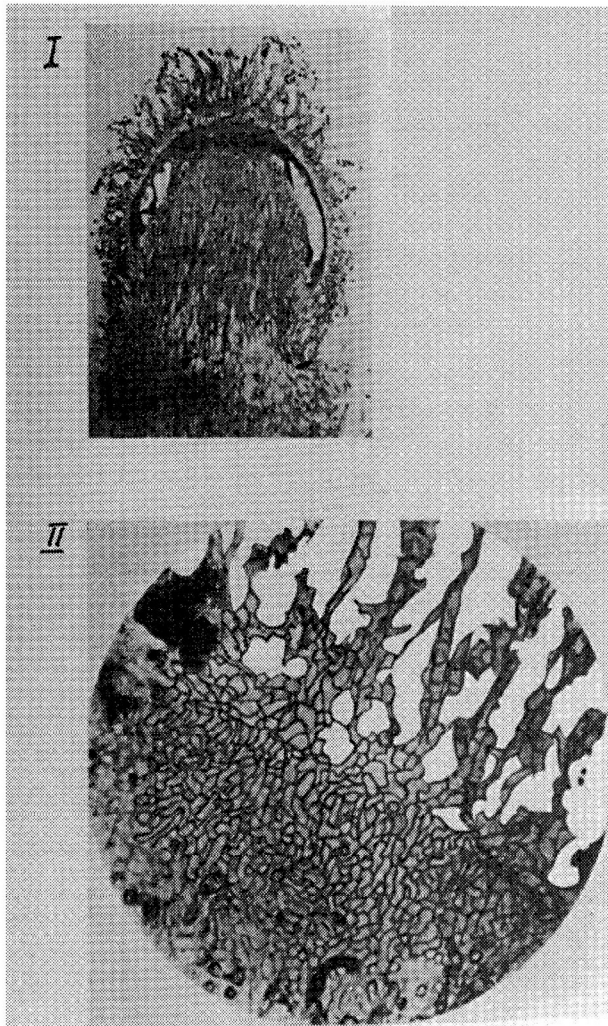
Figure 10
MORPHOGENESIS OF THE ANGIOCARPUS MUSHROOM

The developing fruit body at the early stage again consists of a disorderly plexus of hyphae. As it develops, a geometrically regular arched line looms, located not upon the upper edges of the hyphae, as in the case of the Marasmius (see Figure 9), but below the edges of the hyphae. The next developmental step displays loosening, and finally, falling off of the edges of the hyphae that are above the contour to be formed. Low magnification (I) and stronger magnification (II).
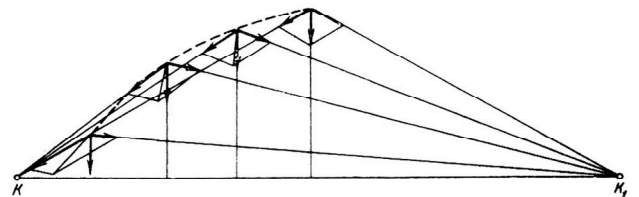
Source: A.G. Gurwitsch 193

Figure 11
MORPHOGENIC FIELD OF THE DISTAL SURFACE OF THE MUSHROOM HAT

If the plane projection of the mushroom's hat shape is considered, there are two point field sources located at the edges of the definitive form of the hat body. These are the sources of forces, whether attractive or repulsive, which decrease in proportion to distance and are summed up according to the parallelogram rules of force composition. Hence, a set of equipotential surfaces can be obtained, one of them corresponding to the major value of the vertical force component (dotted line). This arched line corresponds to the distal surface of the Marasmius mushroom hat, along which the edges of the hyphae are "brushed up." It also corresponds to the barrier line above which the edges of the hyphae fall away in the angiocarpus mushroom.
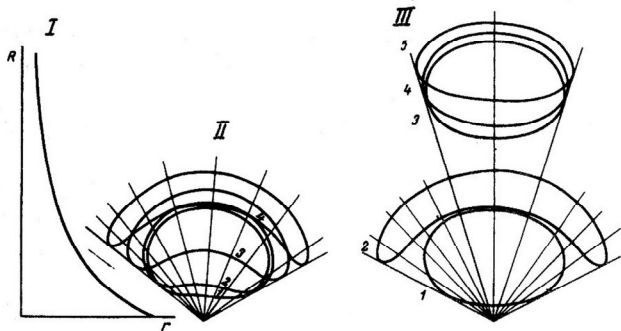
Source: A.G. Gurwitsch 1922

Figure 12
THE MORPHOGENIC FIELD IN THE DEVELOPMENT OF THE TRITON PHALANX CARTILAGE

Changes in the shape of cell nuclei of mesenchymal cells occur with regularity during the development of the triton phalanx cartilage. In the center of a transverse section of the phalanx, the nuclei are round, but they change to bean shape with increasing distance from the center. Beyond a certain critical distance toward the periphery, the shape again becomes round.

The distance r travelled by a point on the surface of the cell nucleus depends on the initial distance R between this point and the field source. This hyperbolic function of the second degree is shown in I. The corresponding calculated changes in the form of the nucleus, as the nucleus becomes more distant from the point field source (1→2→3→4), are shown in II. Drawing III shows changes in the nuclear shape in the central (1→2) and peripheral (3→4→5) areas of influence of the field source.

Source: A.G. Gurwitsch 1930

Figure 13
CHANGES IN THE SHAPE OF THE NUCLEUS ACTUALLY OBSERVED IN HISTOLOGICAL PREPARATIONS

A sagittal section is shown in A, while B, C, D, and E are transverse sections.

Source: A.G. Gurwitsch, Histologische Grundlagen der Biologie, 1930

regularity in the gradual changing of the shape of the nucleus, from round to bean-like, but then, after a further small but critical increment of distance, back again to round.

Two more studies testing the applicability of the field principle to the problem of cytodifferentiation during development were carried out, one by Lydia Felicine-Gurwitsch, Gurwitsch's wife, and the other by Gurwitsch himself.

The object of the former study, titled "Application of the Field Principle for Analysis of the Processes of Embryonal Differentiation" (1924), was associated with the development of the amphibian retina. The main question was whether there are any components in the process of cytodifferentiation which depend on the coordinates (relative to the axes of symmetry) of the differentiating cells within the whole retina layer. Accordingly, histogenesis in the central and peripheral parts of the retina were compared. It was found that the growth of the amphibian retina proceeds by the addition to the retina layer of new cells from the marginal mitotic zones. These young cells are much smaller than the mature rod-cells to which they will be converted as a result of differentiation. Correspondingly, the cells at the central part of the retina are older and larger. Thus, maturation includes both growth and differentiation. At a certain stage of development, a wave of differentiation passes throughout the cells of the whole retina. Therefore, cells in the cen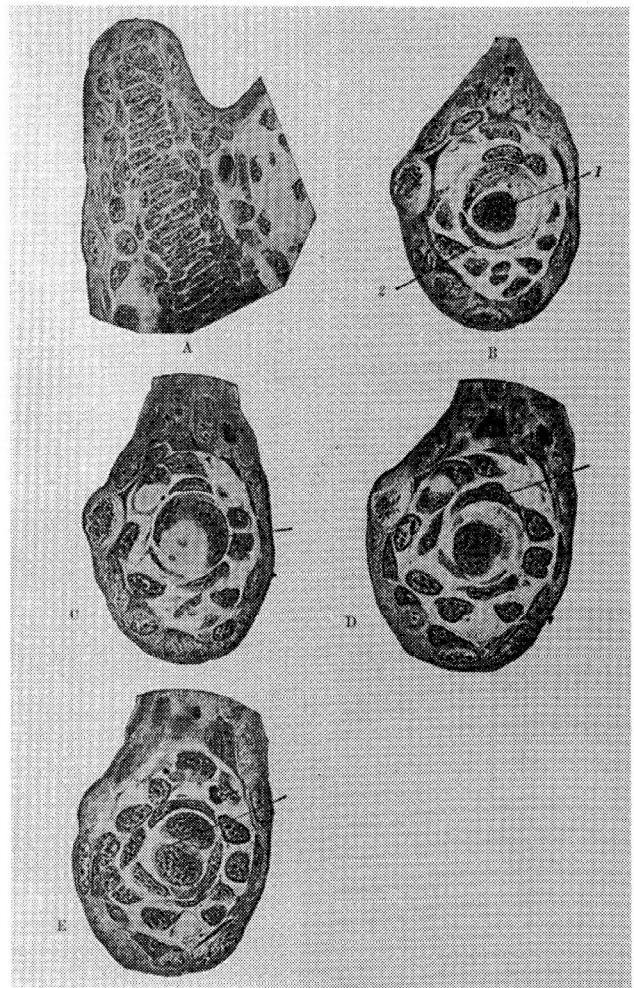tral part of the retina first grow, and then differentiate, while in the peripheral part, the cells first differentiate and then grow (Figure 14). Such varying relationships between rates of growth and differentiation in different cells are a function of the distance of the cell from the center of the retina (exit of the optic nerve).

While in the previous models, morphogenic field action was expressed in cell movements, changes in the shape of nuclei, and other "kinematic" effects, here the field action means directing the cell either to continue growing or to start differentiating, two processes of quite different character. In other words, in the previous models the "mechanism" of the suggested field action, either attraction or repulsion, was more immediately realized through the observed cell movements, while in the case of the differentiation of the retina, the field was seen to be a factor having a much deeper involvement in cellular structure and function.

In a second field model dealing with cytodifferentiation, Gurwitsch analyzed the process of mammalian spermatogenesis
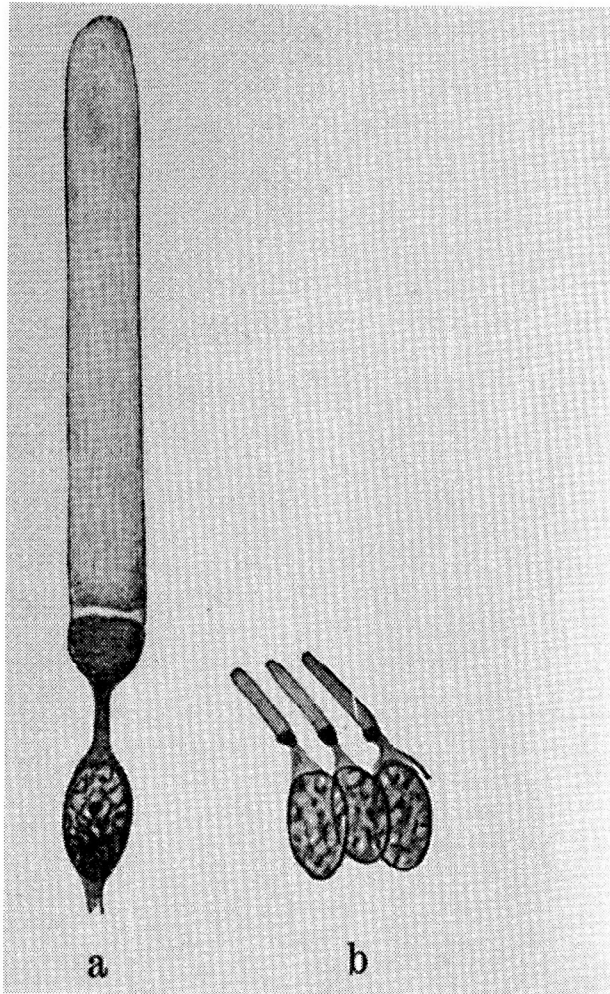
Figure 14
ROD CELLS IN THE RETINA OF A YOUNG FROG JUST AFTER METAMORPHOSIS
A rod cell from the central area of the retina is shown in a; rod cells from the periphery of the retina are represented in b (same magnification).

Source: A.G. Gurwitsch 1930

Figure 15
CONSTRUCTION OF THE MORPHOGENIC FIELD DESCRIBING THE DIFFERENTIATION OF THE HEAD OF A SPERM CELL
Gurwitsch's model is based on the idea that the developing sperm cell is under the influence of some external field whose point source rotates around the cell. The drawing shows three successive stages of differentiation of a sperm cell. Fully formed rat and mouse sperm cells are shown in R and M.

Source: A.G. Gurwitsch 1927

(1927). Differentiation during spermatogenesis combines both drastic changes in general cell morphology and complicated intracellular movements of the cell organelles, such as centrioles, Golgi apparatus, and so on. Both changes in cell morphology and the displacement of organelles are perfectly described by Gurwitsch's model, which is based on the idea that the developing sperm is under the influence of some external field whose point source rotates around the cell (Figure 15).

The models based on Gurwitsch's primary conception of an embryonal morphogenic field, present a mixed collection of abstract constructions. Indeed, the model field can be either attractive (the dynamically preformed morpha of cerebral vesicles and the chamomile floscule), or repulsive (Triton phalanx). Also, its descriptive capacity can work independently, whether attraction or repulsion is ascribed to it (mushroom hats), or the field surface is of paraboloidal or other regular form. It can originate from point sources (Triton phalanx,
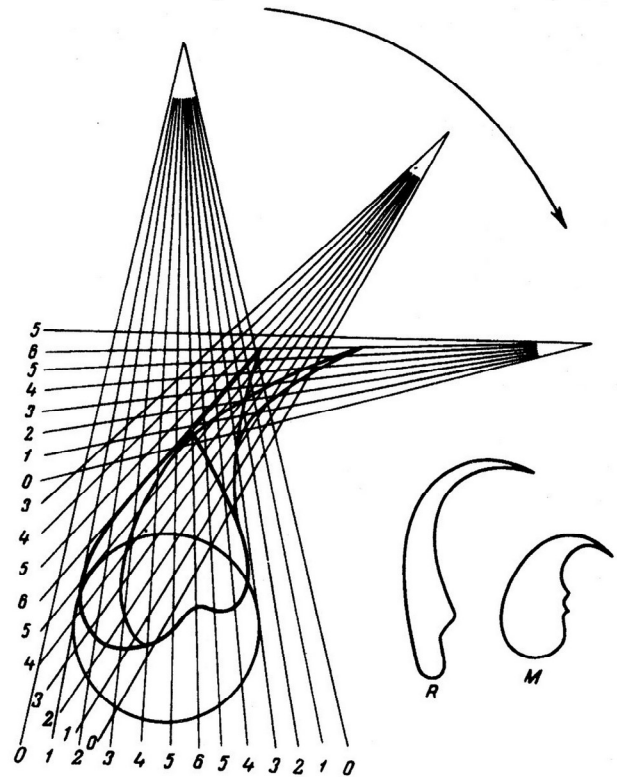
sperm, amphibian retina), or it can be vectoral (mushroom hats). However, in spite of their mixed character, these models are united by the same fundamental principle: A single invariant law describes the development of a specific part of the embryo as a complete macroform during a relatively long period.

However, in spite of the elegance and descriptive capacity of the field models, Gurwitsch himself realized the shortcomings of his primary field conception, emphasizing that this approach was only the first step toward its further development.

First, although the field models are effective in their ability to describe events during a sufficiently long developmental period, none of them can serve as an invariant principle for the whole ontogenetic cycle. For example, a particular formula of the "dynamically preformed morpha" can fairly well describe the development of the shark's cerebral vesicles, but it is not fit for the description of any further development of the same species. In other words, the model may be suitable for a period of development from A to B, but the next period from B to C will need another model. Second, the objects analyzed by the models are rather artificially and arbitrarily delimited from the

whole embryo. Thus, the only, though highly so, valuable principle of these models was the invariant postulate, and the next intention of Gurwitsch was to use it for an adequate description of intracellular processes.

Molecular Prerequisites of the Field Theory: Use of Basic Principles of the Field Theory For Processes Occurring at Molecular Level

From the beginning of his scientific activity, Gurwitsch showed interest in the biological processes occurring at the molecular level, which was exceptional for a histologist at that time. His first work in this direction—which can be considered one of the first studies of molecular biology—concerned regulational phenomena in the protoplasm of amphibian and echinoderm eggs, revealed by means of the centrifugation method, applied for the first time to living things (A.G. Gurwitsch 1904, 1905, 1908). The main finding was that, although all the contents of the eggs were reshuffled by centrifugation, and all the visible structures destroyed, the first stages of development, cleavage and blastula formation, proceeded. The visible structures in the cytoplasm were usually restored, but often development proceeded even without such restoration. Gurwitsch's conclusion was that when destruction of the structure of the cytoplasm is followed by its restoration, it is re-created from certain amorphous (invisible) materials, which are carriers of (are responsible for) living expressions. Gurwitsch proposed that, in the case of reversible perturbations of the initial intracellular molecular organization, certain "dynamic conditions" in the cytoplasm responsible for the organizational specificity remain undisturbed, and restore the damaged molecular organization using deliberately different material (molecules).

Such "interchangeability" of the molecules participating in the morphogenic processes is the expression of the same phenomenon of equipotentiality described by Driesch, now observed at the molecular level. The specificity of the observed processes (in spite of the destruction of the structures normally participating in them) realized through the involvement of other molecules, impelled Gurwitsch to designate the cytoplasm as the "structured process" which underlay his "physiological theory of protoplasm." The application of the regulational principle of Driesch (harmonic regulation) to the molecular level meant that a single cell should be considered as the whole. Accordingly, the notion of equipotentiality when

applied to the molecular level was designated by Gurwitsch as "polyreactivity" (A.G. Gurwitsch 1944). Essentially, this means that there is no predetermination of intracellular compartments: The subcellular entities behave according to their coordinates in the whole cell which, hence, presents a dynamic network (in correspondence with the coordinate network), which determines the fate of the molecules locally involved ("structural process").

These views were supported by experiments in which the application of cooling, starvation, and narcosis to fertilized eggs caused chaotic movements of intracellular organelles, such as centrosomes, mitotic spindles, and so on (A.G. Gurwitsch 1944). Gurwitsch concluded that the harmonic movements observed in a normal cell are caused by a certain factor related to the cell as a whole, and that this factor is not destroyed or inactivated by the centrifugation method, which destroys the visible intracellular structures. Therefore, space-time connections between separate intracellular structures or processes are not the result of any properties of the structures themselves. In general, the experimental factors causing such chaotic movements of the intracellular organelles, such as starvation, cooling, and narcosis, directly or indirectly decrease the intensity of energy metabolism. For Gurwitsch, this was the starting point for a crucial leap of thought, that the metabolic energy is necessary for the maintenance of this intracellular invisible structurality. Further development of this idea led to the conception of two distinct kinds of molecular associations in living systems.

The associations of the first kind are stable molecular formations constituting visible and invisible structures, in which the molecules are bound together by means of ordinary chemical bonds: covalent, ionic, hydrogen, and Van der Waalsian. In order to destroy these structures, external energy must be applied to break the bonds.

The associations of the second type are unstable molecular constellations, in which the molecules are not connected to each other by any of the above-mentioned bonds, but their association within the constellation is supported by a continuous influx of energy. This means that if for any reason the energy influx ceases, the constellations immediately dissociate. Such labile molecular associations, within which the molecules are not bound by any known chemical bonds, and whose existence depends on a continuous influx of metabolic energy, was designated by Gurwitsch as "unbalanced molecular constellations." The word "unbalanced" is perhaps an in-
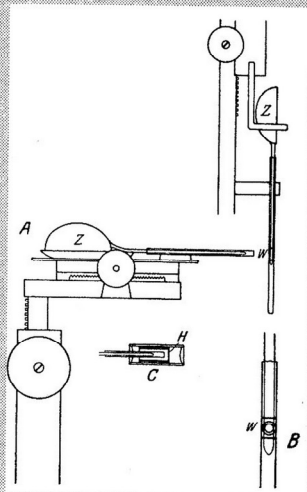
From archives of L. Beloussov

The Gurwitsch laboratory at Simferopol (1923-1924). Gurwitsch is first row, second from left; his wife is third from left.

Gurwitsch's Famous 'Onion Experiment'

The cells at the root tip of a growing onion divide quickly. During growth, the circular cross-section, characteristic of the whole root, is maintained. Although individual cell divisions appear to occur in an unordered, even random distribution, the number of divisions in all directions from the axis must nevertheless be approximately equal. The root would otherwise not have a cylindrical form.

Gurwitsch supposed that at least some of the cells must be emitting light that regulated the rate of division of the other cells; he proved it by means of the experimental setup shown here. The roots (W) of two onions (Z) were positioned perpendicularly, so that the tip of one root pointed to one side of the other root. He then examined under the microscope the second root, at the site facing the tip of the first root. He was able to establish a statistically significant increase in cell divisions there, compared to the opposite, "unirradiated" side. This effect disappeared when he placed a thin piece of window glass between the two roots, and reappeared when he replaced it with quartz glass! That meant that ordinary glass is opaque for mitogenetic radiation, while quartz glass is translucent. Hence electromagnetic radiation must be operative, and ultraviolet light in particular, since it passes through quartz, but is stopped by window glass.
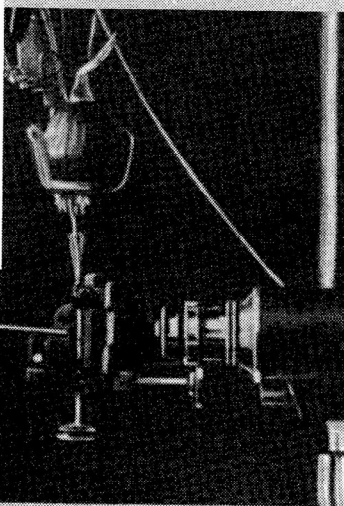
Source: A.G. Gurwitsch, *Das Problem der Zellteilung* (The Problem of Cell Division), 1926

Similar ideas concerning the unbalanced state of the living system were developed independently by E. Bauer (1935), who considered the general intrinsic property of the protein molecules of the living system to be a "steady unbalanced state," which is expressed in their deformations. Accordingly, the metabolic energy is transformed into a certain "structural energy" in deformed (structurally altered) protein molecules, which is utilized for the realization of functions of the organism. An adequate experimental examination of this hypothesis was seen by Bauer as an attempt to reveal this structural energy, which is released as the living system dies.

Gurwitsch often indicated the closeness of his and Bauer's views on the unbalanced state of the living system, and emphasized Bauer's priority in the general elaboration of this conception. However, there was an important difference in the representation of a substrate for the realization of the principle of the unbalanced state in living systems. According to Bauer, the state relates to the internal (deformed) structure of the protein molecules themselves, while Gurwitsch, on the basis of strong evidence, came to the conclusion that not only separate molecules, but actually the labile molecular constellations, are in the unbalanced state, forming the entire molecular continuum throughout the cell.

The evidence Gurwitsch used to come to such a conclusion related to the phenomenon of degradational mitogenetic radiation (A.G. and L.D. Gurwitsch 1937a; A.G. Gurwitsch 1937b). Unbalanced constellations need a continuous influx of metabolic energy for their existence, and at any moment possess the required amount of accumulated potential energy (position energy). Moreover, the involvement of a high number of protein molecules in a constellation, and the relationship to the entire continuum create the conditions for the formation of common energetic levels, permitting the migration of common energy within the constellations, with the possibility of its summation at certain points of the continuum. Certainly, the area of such energy migration had to be within supra-molecular distances. These considerations shaped the experimental approaches aimed to reveal the accumulated potential energy.

The first approach, realized by Anna A. Gurwitsch (1947), consisted of experiments on protein solutions in which the protein molecules were oriented by applying physical factors, such as a constant flow of the solution, or a weak electric field, or a strong magnetic field. In the first two cases, a so-called secondary mitogenetic radiation was detected from both the flowing protein solution and the solution under the influence of the electric field. The emission of secondary mitogenetic radiation is known to be a consequence of energy migration along oriented molecules (A.G. Gurwitsch 1932, 1944; A.G. and L.D. Gurwitsch 1931, 1945, 1948). The protein solutions in the experiments using the magnetic field were then exposed to infrared radiation. This resulted in an emission of mitogenetic radiation from the solution. This can be explained by the fact that the infrared energy brought to the protein solution was shifted up to the ultraviolet level (the mitogenetic radiation). The general suggestion from these experiments was that the above-mentioned physical factors caused a spatial orientation of the protein molecules in solution, leading to the formation of common energetic levels, providing energy migration and summation.

The second approach was associated with the problem stated first by E. Bauer (1935) and then by Gurwitsch (1937b), of revealing the energy spent for the support of the unbalanced state of the living system. This problem was brilliantly addressed via the discovery of the phenomenon of degradational mitogenetic radiation (A.G. Gurwitsch 1937a, 1937b). The difference between Bauer's point of view (the unstable state relates to individual protein molecules, and the metabolic energy is expended for their deformation), and that of Gurwitsch (the unbalanced state relates to the molecular constellations and the metabolic energy is expended for their current support), determined the experimental design.

It was suggested that this hypothetical energy might be captured in the form of mitogenetic radiation. According to Gurwitsch's conception, the release of the energy accumulated in the unbalanced molecular constellations can be precipitated either by stopping the influx of metabolic energy (followed by a collapse of the unbalanced constellations, with the subsequent release of the potential energy), or by "mechanical" destruction of the constellations (followed by the destruction of the common energetic levels, with subsequent release of the potential energy). Such a combination of "metabolic" and "mechanical" approaches is not applicable to Bauer's conception, which is compatible only with the former one.

The results strongly confirmed Gurwitsch's conception. All of the animal and plant objects studied displayed a short burst of mitogenetic radiation in the case of both metabolic (sharp cooling or light narcosis), and mechanical degrading factors (centrifugation or weak alternating current). Importantly, if any of the degrading factors was immediately followed by any other, it did not cause additional mitogenetic radiation. This means that all the degrading factors used in the experiments had the same target: unbalanced molecular constellations. If the constellations were already destroyed by any of the above factors, repeated application of the factor would have no effect. The degrading action of the factors used was fully reversible: After the cessation of the factors' action, a full physiological restoration of the unbalanced state was observed. Gurwitsch's conclusion was that the unbalanced state of the intracellular molecular substrate was associated with the protein constellations, rather than with individual protein molecules.

The influx of metabolic energy is an absolute condition for the existence of the unbalanced molecular constellations. Their existence is organized by a certain dynamic factor whose action, although connected with a continuous utilization of metabolic energy, is quite independent. Since precisely this factor determines the specific orientation of the protein molecules within the constellation, and the orientation is connected with the specific spatial arrangement of the protein molecules relative to certain coordinates, this dynamic factor can be defined as a field factor. Essentially, the action of the "orienting" field factor should be expressed as limitations it imposes on the free chaotic movements of the molecules. Hence, the action of the field factor is expressed in a certain vectorization of the chaotic movement of the protein molecules.

This was the basis for the new general conception based on the same principles, which could now combine the events occurring at all three levels of biological organization: organis-mal, cellular, and molecular. The first drafts of the new conception of the vectorial biological field were outlined by Gurwitsch in autumn 1941, in besieged Leningrad, and the completed theory was published in 1944 in Moscow, and then in 1947 in Leyden.

To be continued

References

A.W. Anikin, 1929. "*Das Morphogene Feld der Knorpelbildung,*" W. Roux' Archiv für Entwicklungsmechanik, Vol. 114, pp. 549-577.

E. Bauer, 1935. *Theoretical Biology.* Moscow: USSR Institute of Experimental Medicine Publishing House.

L.V. Beloussov, 1980. *Introduction to General Embryology.* Moscow: Moscow University Publishing House. In Russian.

H. Driesch, 1908. "Studien über das Regulationsvermögen der Organismen," *Archiv für Entwicklungsmechanik,* Vol. 26.

——, 1915. *Vitalism: Its History and System.* In Russian; the authorized translation from German, by A.G. Gurwitsch.

L.D. Felicine-Gurwitsch, 1924. "Die Verwertung des Feldbegriffes zur Analyse der Embryonaler Differenzierungsvorgänge," *W. Roux' Archiv für Entwicklungsmechanik,* Vol. 101, pp. 40-52.

A.A. Gurwitsch, 1947. "Attempt to Construct a Model of Non-balanced Molecular Constellations and Degradational Radiation," in: *Papers on Mitogenesis and the Theory of the Biological Field,* edited by A.G. Gurwitsch (Moscow: USSR Academy of Medical Sciences Publishing House), pp. 92-101. In Russian.

A.G. Gurwitsch, 1904. "Über die Zerstörbarkeit und Restitutionsfähigkeit des Protoplasmas in Echinodermeneiern und Amphibieneiern," *Verhältnis der Anatomischen Gesellschaft,* 146-151.

——, 1905. "Über die Zerstörbarkeit und Restitutionsfähigkeit des Protoplasmas der Amphibieneier," *Anatomischer Anzeiger,* Vol. 27, pp. 481-497.

——, 1908. "Regulation Phenomena in the Protoplasm," *Proceedings of the St. Petersburg Naturalist Society,* Vol. 37, pp. 140-189. In Russian.

——, 1910. "Über Determination, Normierung und Zufall in der Ontogenese," *W. Roux' Archiv für Entwicklungsmechanik,* Vol. 30, pp. 133-193.

——, 1912. "Die Vererbung als Verwirklichungsvorgang," *Biologische Zentralblatt,* Vol. 32, pp. 458-486.

——, 1914. "Der Vererbungsmechanismus der Form," *W. Roux' Archiv für Entwicklungsmechanik,* Vol. 39, pp. 516-577.

——, 1922. "Über den Begriff des Embryonalen Feldes," *W. Roux' Archiv für Entwicklungsmechanik,* Vol. 51, pp. 383-415.

——, 1927. "Weiterbildung und Verallgemeinerung des Feldbegriffes," *W. Roux' Archiv für Entwicklungsmechanik,* Vol. 112, pp. 433-454. Festschrift für H. Driesch.

——, 1930. *Die Histologischen Grundlagen der Biologie.* Jena: G. Fischer Verlag.

——, 1932. *Die Mitogenetische Strahlung.* Berlin: G. Fischer Verlag.

——, 1937a. *Mitogenetic Analysis of the Excitation of the Nervous System.* Amsterdam.

——, 1937b. "Degradational Radiation from the Central Nervous System," *Arkhiv Biologicheskikh Nauk,* Vol. 45, pp. 53-57. In Russian.

——, 1944. *The Theory of the Biological Field.* Moscow: Sovetskaya Nauka Publishing House.

——, 1947. "Une Theorie du Champ Biologique Cellulaire," *Bibliotheca Biotheoretica,* ser. D, Vol. 11, pp. 1-149.

A.G. Gurwitsch and L.D. Gurwitsch, 1931. "Analysis of Secondary Mitogenetic Radiation," *Arkhiv Biologicheskikh Nauk,* Vol. 31, pp. 85-87. In Russian.

——, 1937. "Degradational Mitogenetic Radiation," *Bulleten Experimental'noy Biologii i Meditsiny,* Vol. 4, pp. 459-460. In Russian.

——, 1945. *Mitogenetic Radiation: Physico-chemical Basis and Applications in Biology and Medicine.* Medgiz Publishing House. In Russian.

——, 1948. *Introduction to the Doctrine of Mitogenesis.* Moscow: USSR Academy of Medical Sciences Publishing House. In Russian.

R. Harrison, 1918. "Experiments on the Development of the Forelimb of Amblystoma, a Self-differentiating Equipotential System," *Journal of Experimental Zoology,* Vol. 25, p. 413.

W. Roux, 1895. *Gesammelte Abhandlungen über Entwicklungsmechanik der Organismen.* Vols. 1 and 2. Leipzig.

H. Spemann, 1936. *Experimentelle Beiträge zu einer Theorie der Entwicklung.* Berlin.

H. Spemann and H. Mangold, 1924. "Über Induction von Embryonalanlage durch Implantation artfremder Organisatoren," *Archiv für Entwicklungsmechanik,* Vol. 100, pp. 599-638.

For further reading

L. Beloussov, 1997. "Life of Alexander G. Gurwitsch and his relevant contribution to the theory of morphogenetic fields," *International Journal of Developmental Biology,* Vol. 41, pp. 771-779.