20 years, molecular techniques have completely transformed our knowledge of the ways in which the members of a population differ from one another genetically. Only in the past few years has it become possible to determine the sequence of DNA molecules. At present, information is coming in so fast that many of us are suffering from indigestion. When the facts have been digested, some of the controversial issues of the past 20 years are likely to have been settled.

A second, and ultimately decisive, way in which the gap between physics and biology is being bridged is through a study of the origin of life. To understand the origin of life would be to understand how physico-chemical processes can give rise to biological ones. Some questions which have to be answered are among the following. How can a sufficiently accurate mechanism of hereditary replication arise? How did the genetic code, and the resulting distinction between a replicating genotype and a mortal phenotype, originate? What was the origin of individuation, whereby one organism was separated off from others? The aim is to answer these questions in terms of the kinetics of chemical reactions. The article by Kuhn and Waser shows that encouraging progress is being made; indeed, it may be that in retrospect we shall see that the decisive answers to at least the first 2 of these questions have already been given at the level of theory, even if the processes have not yet been fully realized experimentally.

Of course, not all progress in evolutionary biology is concerned with its reduction to physics and chemistry. The article by Stebbins shows how biologists are constantly seeking higher level generalizations. There is everything to be said for striving to show the logical consistence of physics and biology, but no reason to abandon the search for biological laws.

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Complex-irreversibility and evolution

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Summary. Both, irreversibility and evolution, imply order in time. It is argued that the only possible concept of time is a 'system-specific time', and that order in time is convertible into order in space and vice-versa. While life-less, complex systems are irreversible because of their complexity and, hence, not repeatable, living systems are reproduced by irreversible copy-reproduction and by coding. This mode of reproduction results of necessity in an arrow of time of growth and increasing complexity with death as its antagonist, and in obligatory spatial asymmetry. This arrow of increasing organic complexity is simultaneous with, and independent of, the arrow of increasing entropy. – A generalized, organic hierarchy is proposed as the model to study higher evolution. This hierarchy reproduces itself by differential rates of reproduction of its subunits within and between the various hierarchical levels of organization. Phylogenetic change is brought about by a change in this hierarchy's specific phase pattern of growth. Continuous and discrete organization is defined, and it is shown that specific relations between continuous and discrete levels within the hierarchy result in accumulation of neutral alleles. This accumulation is due to complex-irreversibility and causes genetic stabilisation, i.e. heritability, of the species-specific morphology of organisms.

I. Time is system-specific

Both 'irreversibility' and 'evolution' are concepts in which time is intrinsic. For a valid model of organic evolution an agreement must be reached upon the meaning of time.

The simple, and purely empiric proposition I am going to make is, that there can be no generally valid concept of time; that, whatever time order there may be, is only pertinent to the type of system actually under observation.

If we walk along a road and see it disappear over the horizon, we know that we still have to go a long distance until we reach that particular point. We may want to measure this distance in terms of kilometers or meters. We perceive extension in space and measure it by units of extension. Similarly, we experience force or energy, qualify it by the respective sense organs and measure it in the appropriate units (temperature, pressure, sound, light, etc.). If, however, we want to know how long we talk on the telephone, we have to watch how many times the second hand of a watch rotates over the dial. We perceive time as changed energy patterns in space and measure it by counting repeated patterns of change. We have no sense organs to perceive 'time per se', and hence no

possibility of imagining it, we have a *memory* that registers changed energy patterns in space[2]. This indirect perception of time leads to the conclusion that time order is specific for the system under observation: 'every system makes its own time'[3], and further, it means that order in time may be converted into order in space and vice-versa. For instance, annual periodicity in growth of trees of the temperate zone leads to fairly regularly spaced growth rings in woods from this region. Now, many tropical trees also display reasonably regular growth rings and, incidentally, regular branching patterns. They represent periodic efforts of growth if growth is measured in terms of biomass or perhaps number of mitoses. However, the stimuli which trigger these growth periods may be irregularly spaced if plotted on an annual time axis. (Growth dynamics in tropical woods is as yet poorely understood; exceptionally cool days or specific water levels in inundation forests etc. may initiate florescence and growth periods). Distortions between 'system-specific times' are not a priviledge of Einstein's theory of relativity, they occur inevitably whenever units of one kind of system serve as measurement for a different kind of system.

II. Complexity and repeatability

1. Complexity. The complexity of a given system is measured by counting the number of categories of sub-units and the number of sub-units in each category, and, if necessary, number and categories of links between sub-units. This information may be converted into 'probability for a specific state of the system'.

2. Order. It is generally agreed that order is somehow connected with repeated elements or patterns. Every measurement, for instance, consists of counting similar unit-intervals. Order in space is given in terms of symmetry (n-fold, radial, translational, bilateral, etc.), and apparent permanent states on the macroscopic level are maintained by oscillation of vectors on the level of infra-structure. Even the ordering effect of laws, conventions, axioms and principles, etc., depends on repeated statement, teaching and tradition.

If, then, we want to understand the order of dynamic systems, we must ask for the basic mechanisms that can generate repeats.

3. Repeatability in inorganic systems. For inorganic systems, classical physics has given its basic answer: elementary physical processes are in principle reversible and therefore repeatable. Swinging pendula and bouncing balls may illustrate the case (assuming that the process is friction-free; fig. 1). Planets might just as well cycle in opposite direction. Movies of such processes, if copied with right-left inversion, or if shown in reverse, display the same pattern as 'normal' demonstration. Time has no arrow and space has no screw[4] (the symmetry conditions of particle physics need not concern us here)[5]. Repetitions of macroscopic states of large populations of molecules, such as cristallization and dissolution, or the water cycle between earth and atmosphere by evaporation and condensation, rely on the reversibility of elementary processes between similar sub-units.

Repetitions by reversion have the general, and highly significant, property that they do not accumulate in space. Each reversal destroys the former state. Yet, the very fact of reversibility means that the system as a whole does not get lost.

Next, we consider a somewhat more complex process than a bouncing ball: two ideally elastic balls with independent vectors happen to collide (fig. 2). Then they move away from each other, never to meet again.

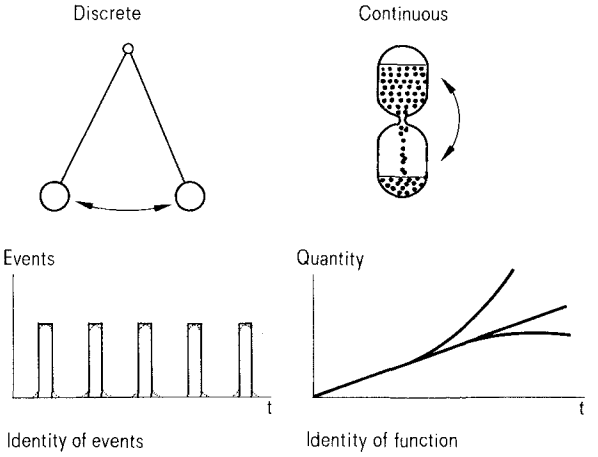

Figure 1. Repeatability by reversion in elementary, physical processes, and interpretation of a system as either discrete or continuous.

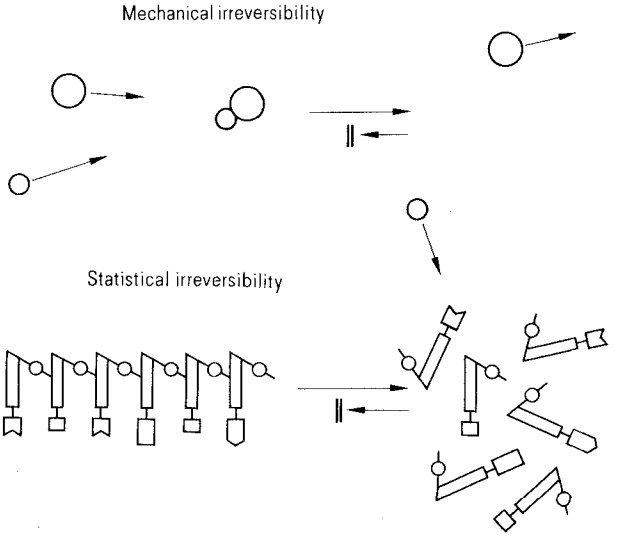

Figure 2. Non-repeatability of a complex, single, mechanical event such as collision by chance of 2 objects (above); and of highly complex statistical systems such as re-assembly of a specific nucleic acid chain (below).

In actual fact this system is vastly more complex than meets the eye if we concern ourselves with reversibility. To assess the probability of reversal we would have to include all objects within defined distance that might reverse the vectors at defined moments. We would find that the so determined probability is, for all pratical purposes, nil. We remember that we deal with lifeless systems, there is no intelligence that places reversing obstacles in appropriate places. Filming the process of collision, we find that we also could view this strip in reverse sequence; the film does not reveal in which direction collision occurred. The classical symmetries of an elementary process are not violated. If, however, somebody is showing a movie with a sequence of precise reversals, we know that he is cheating: he either made most careful experimental arrangements, or, more likely, he produced multiple copies of a symmetrically copied, unique process. *Complex, lifeless systems are not repeatable, because they are irreversible.* They are unique, purely circumstantial events, which do not violate the classical physical laws, and add no further insight that might lead to new laws in theoretical physics.

Approaching biology we look at single-stranded DNA (fig. 2). Its backbone is composed of regularly alternating pentose-phosphate links resulting from direct, antagonistic forces. Like any other crystal, this structure can be decomposed and reassembled again; the process is reversible and hence, repeatable. However, there are no vectors between the 4 bases that would force them into specific sequence. The absence of force between the parts which constitute the category of complexity under consideration (base sequence in this case) is responsible for the radomness of the resulting pattern. Chains of only very moderate length have a negligible chance of being reconstituted with identical base sequence. This system is not repeatable because of its complex-irreversibility. Energy is not the problem in these considerations, we look at open systems for the merely practical reason that systems are, in general, open. The problem is that there are too many possible space cells for each of the individual bases. Pattern in space is the problem, or, if we look at the process of assembly, there are too many bases for each single position in time. Hence, a general principle of complex-irreversibility can be formulated: *Lifeless, complex systems are irreversible whether they are open or closed.*

Suppose that the sugar-phosphate complex in figure 2 stands as a symbol for any kind of small molecule and the 4 bases merely symbolize 4 possible energy states of such molecules. Further, linear sequence merely represents any specific, momentary arrangement in space, and we assume that the molecules are arranged according to descending energy states: highest energy states to the left, lowest to the right. This momentary pattern in space now disintegrates, and, as was the case for the base sequence in DNA, the small molecules would not arrange themselves again in the order of diminishing energy states. It would need a 'Maxwell demon' that can see individual molecules, and can place them appropriately[6]. This is a model for the second law of thermodynamics, for the law of increasing disorder or entropy. Even if we dismiss individual complexions and look only at reversibility between 'hot gas' and 'cold gas' in 2 containers, we would still need an engineer to build us a machine with containers, valves, alternate heating and cooling, or with pistons to push the gas to and fro. But there are no Maxwell demons and engineers in lifeless systems.

We see now that the law of entropy represents merely one specific kind of complex-irreversibility, the only kind theoretical physics has expressed in terms of a law. The second law of thermodynamics presents a case of specific complex-irreversibility because it applies to molecules and sub-molecular states of matter only, and not to any assembly of objects, and because the category of complexity considered is confined to energy states. However, at the same time, the second law of thermodynamics is a general, universal law, in that all matter consists of molecules and sub-molecular particles which are characterizable by energy states. This simultaneous truth of specificity and universality is the source of much confusion in biological research and argument. We can always assess a system in terms of entropy without, however, gaining a shred of useful information on the pattern analyzed. In biological systems specific positions in space and time of specified units determine the cause of events, not energy states between these relevant units; random sequence is the result of absence of energy, also in the case of a specific random sequence.

4. Repetition in organic systems. Living systems are complex and irreversible and yet multiply at a sometimes appalling rate. Biochemistry and molecular genetics have come to an understanding of the complex mechanisms that reproduce organic pattern. There is 'copy-reproduction' by hydrogen bonding between specific base pairs in transversal direction. By this mechanism the system transcends to order on a higher level of structure: a complex random pattern of astronomical initial improbability is repeated in time and space; persistence of this pattern is due to repetition. As the copy mechanism itself is complex, several independent input vectors leading to coordinated output, it is complex-irreversible[2]. There are very precise physical conditions for the persistence of the thus repeated pattern:

a) it must be reproduced before it disintegrates;
b) its rate of reproduction is (initially) larger and (later) at least equal to its rate of decay.

If these conditions are not met, this pattern is irrevocably lost. Thus enters an arrow of time of irreversible growth, and its equally irreversible antagonist, death.

Even the shortest and perhaps most pristine nucleic acids are composed of some 70 bases (t-RNA)[7,8]. Inevitable small, local accidents may change, add or delete a nucleotide. The structure and function of the macro-molecule remains essentially the same while suffering a certain range of variation. Only complex systems can change 'a little', can evolve. Due to random mutation, the arrow of time of growth and accumulation of organic matter is also an arrow of time of increasing complexity, subject to a positive feed-back: complexity begets complexity. Ever more of something, ever more of different things, élan vital, invention, Parkinson's Law, greed, empire building, more and better arms .... 'myne Fru, de Ilsebill ...' (Grimm 1812)[9].

Our complex, organic system is thus subject to two simultaneous arrows of time, the arrow of entropy and the arrow of evolution. The first is counteracted by a continuous input of free energy[10], the second by death. Thus, already on the lowest macromolecular level of organization living systems monitor their separate orders of time.

Simple copy-reproduction of poly-nucleotides may at best have occurred at the very beginning of precellular evolution. From virus to man with his industrial production, copy-reproduction is combined with 'coding'; there is what may be called 'reproduction via analogon' (fig. 4). In the context of reproduction, (and only in this context), analogy is defined as follows: Two separately identifiable patterns are related by analogy if the existence and frequency of the one is correlated with the existence and frequency of the other in the absence of direct forces between the two patterns that could cause the correlation. That is, correspondence between codon and analogon came about, and is maintained, by reproduction of an initial random event. There is no direct chemical specificity between a given trinucleotide (genetic codon) and its corresponding amino acid[7], nor is there a direct energetic relation between an 'U' in a written text and the respective sound waves when it gets pronounced.

There are 2 essential, physical conditions for efficient coding: for unique specification of the analogon the codon must be asymmetrical, and for specification of complex series of analogons the components of the code must allow for free arrangement; no specific forces are allowed between components of a code that would force them into regular patterns. Thus, absence of specific forces is not only the normal state between codon and analogon, but also between the components of the code. The pattern of forces that link a code is not related to the information of the code.

Asymmetry of codes is easily verifiable wherever codes occur. Three-dimensional code structures, like the genetic code, and immuno-proteins, are clearly chiral (l-amino acids and nucleotides, 5′→3′ asymmetry in 'reading' the genetic code, α-helices). Human-cultural codes are usually applied to surfaces; the axis of gravity (top of page) and a conventional reading direction define the other 2 spatial dimensions. Thus we find that UUC→leucine; CUU→valine; hence, for the genetic code UUC≠CUU, and similarly: 801≠108; tool≠loot; 9≠6; b≠d; etc.

The conditions of molecular chirality and forcelessness add a set of specific, biophysical principles to the organic world. All apparent bilateral symmetry in organisms is 'pseudo-symmetry'[2,11], usually imposed by necessary, mechanical function as is for instance straight line movement with a steady body axis in animals which orientate themselves by vision[12]. It means that on all levels of organic, hierarchical structure, from mitotic chromosome separation to the symmetrical morphology of vertebrates with their asymmetrical internal anatomy, special morphogenetic mechanisms must monitor symmetry conditions. Chirality, not parity, is the basic condition of embryos.

The condition of forcelessness between codon and analogon and within codons is responsible for the apparently forbidding barrier which most theoretical physicists refuse to cross. So, the 'theoretical physics' of complex, organic matter is still unwritten. Phase-spatial patterns are causative, the energy input merely permissive. Pattern determines energy vectors, rather

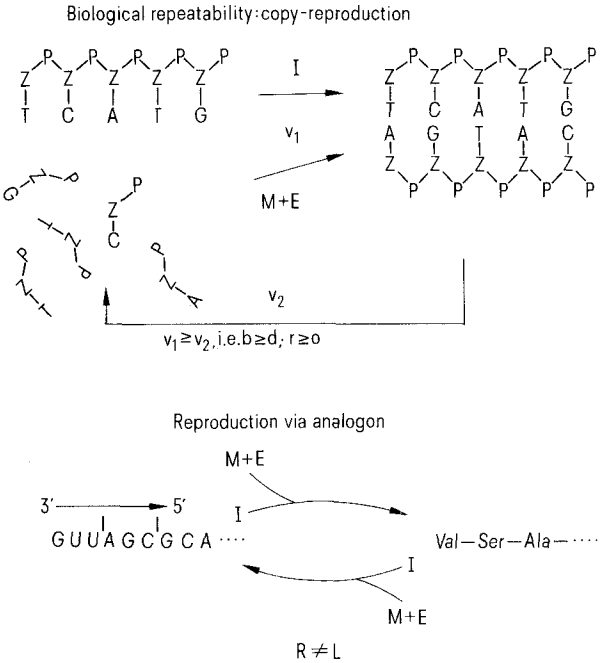

Figure 3. Biological repeatability of complex systems. Above: copy-reproduction of nucleic acid chains (P = phosphate; Z = sugar; C, T, G, A = the 4 bases); I = input vector of information; M + E = input vector of material and energy; v_1 = rate of assembly; v_2 = rate of decay; b = birth rate; d = death rate; r = b − d = intrinsic growth rate. Below: reproduction via analogon or code as in the translation of a nucleic acid chain (m-RNA) into the corresponding peptide chain, and its dependence on structural asymmetry (5′→3′; R≠L: loss of right-left parity).

than vice-versa. Biological conditions violate the stickiest, most persistent physical beliefs, for instance that the parts explain the 'whole'. The distribution of bases in coding DNA, and of letters in written text, for example, is still essentially random, yet may cause the most rigorously specified, ordered processes on higher levels of structure; for instance a spider's web, an orchid, or the formulation of a mathematical law. Analyzing DNA per se can never lead to prediction of organismic form and function. Only the knowledge of the context between codons and analogons can explain the position of a specific base in a specific position; the knowledge of grammar helps us to avoid errors in writing. Higher hierarchical levels explain the physical patterns on their lower levels, and randomness is not disorder. Information theory is not the answer; any method that dismantles biological complexity to the level of bits has sunk far below the hierarchical levels of structure that could allow for causative explanations.

Thus, we find that the appearance of mechanism that can generate repeats of complex patterns introduces a set of specific physical principles which apply already on the macromolecular level of structure. Biology, and biophysics, starts with mechanisms that can generate repeats of complex patterns. This is a clear cut boundary between live and lifeless systems. Human enterprise, industrial production and machines are the product of large numbers of interacting proteins, just as is the replication of DNA. As evolution proceeds towards ever higher, hierarchical levels, these specific biophysical principles get purified to almost the degree of platonic types. The absence of a causative relation between the pattern of energy input and output becomes total; with the same sandwiches in their stomachs, the members of a ballet may produce random havoc on the stage or the most pleasing, symmetrical configurations; the same waterwheel, steam engine or electromotor may grind cereals or cut logs. The obscurity of the relations between input and output vectors matches the obscurity of the 'black box' in between.

III. Neutral, genetic variation and complex-irreversibility in higher evolution

1. Choice of a model

The question, then, is whether we must despair to such an extent that we reduce our comprehension of higher evolution to the theory of mutation and selection. That accidental changes may, or may not, permit an organismic form to persist, seems somewhat thin as an explanation for the evolution of the biosphere, no matter how much mathematical flesh one may arrange around this simple bone. What we really would like to understand is the phylogenetic sequence of *forms*; why does a given ancestral form branch out into this particular spectrum of its descendents? What can genetic change do to a particular morphotype?

We set out into this kind of enquiry by returning to the first section of this paper, where we found that every system 'makes its own time', and that time order is translated into order in space, that phase order of growth results in specific form[13]. Every phylogenetic change of form reflects a change in the dynamics of growth (under the assumption that the structural elements of growth remain invariant: this assumption shall hold throughout these considerations, i.e. for simplicity we consider enzymes as dynamic systems and disregard changes of structural proteins).

The second principle we choose as a basis for argumentation is, that all organic systems are hierarchical in their structure, composed of various levels of subunits, and that growth and reproduction of a given hierarchy is brought about by reproduction of its subunits at all inferior levels. Hence, the anatomy and morphology of organisms, as well as the structure of communities in given ecosystems, is the function of the phase order of reproduction between their constituent sub-units (cell-organelles, cells, tissues, organs, segments, individuals, colonies, populations, communities). Therefore, phylogenetic change is interpreted as the result of a phase-shift between the rates of reproduction of sub-units within, and between, hierarchical levels of the organic system[14].

The basic model, then, is the organic hierarchy with its time order of growth.

2. Causative and permissive levels of the hierarchy

The causes that lead to the output pattern of a complex mechanism lie generally on the highest level of structure and function. If I want to know why a dog can cross a road in a straight line I look at the form of the dog as a whole, at the position and number of its legs and at their phase order of movement. I find a high level of bilateral symmetry in form and leg movement, an anterio-posterior translation (fore and hind limbs), and on examining joints and muscular attachments, I find that there is little possibility for lateral wobble. There is no need to dive into tissue structure and cytology. The conditions on the inferior levels merely have to permit the function on the higher levels. There are usually several options on lower levels of structure that allow for the same output function on higher levels. Cats and horses may also cross a road in a straight line. The more complex a hierarchy, the greater is usually the wobble between the ultimate, *causative* level of function and its various, inferior, *permissive* levels. Permissive levels may not allow the function on higher levels, because of specific defects, but they do not cause higher level function in absence of defects. These considerations apply to any hierarchical level within a complex system we may choose as the 'highest' for our analysis.

For instance, if we study the differentiation of scales on moth wings, the causes for their pattern lie on the level of cell differentiation, such as relative position, number of endomitoses, etc.[15]. The inframechanism of endomitosis merely permits the genesis of different scales, or, in case of a defect, may not permit it; the cause for various kinds of scales lies in the number of endomitoses that actually occur.

We come thus to the conclusion that isolation of a specific defect on the permissive levels of a system does not allow for the deduction that the functional state of this isolate is, or ever was, a cause for the pattern of function on the higher, hierarchical levels of this system.

The distinction between causative and permissive is rooted in the method of analysis of a hierarchical system. If we ask why the thoracic segments of higher insects fused, we single out this particular function for mechanical analysis. We do not consider the 'wobble' that insects with separated thoracic segments may also function successfully. Causal relations are, by definition, exclusive and specific, on whichever level of the hierarchy the analyzed function may be placed. The lower levels of structure then appear merely as the materials, which, evidently, allow for the function under analysis. This is common practice in physics and technology. The 'Zeppelin' broke down because of resonance, but nobody would argue that the rotation of its motor was caused by the absence of resonance. This is, however, exactly the kind of argument the theory of mutation and selection is based on. All laboratory mutants are defective, and so are the mutant genes in domesticated plants and animals; hardly any of these varieties would be successful in the wild. This material is taken as evidence for the argument that individual selection of specific, fit alleles is the cause for form and function in higher organisms.

This explicit effort to establish direct, causal relations between DNA and form and function in higher organisms must fail, because the argument jumps over the non-specifities of the wobbles, accumulated within and between all levels of the hierarchy. Molecular geneticists know how much consideration is due to the wobble of the genetic code alone. If 4 codons signify the same amino acid, selection for a specific one of these 4 codons is impossible. Thus coding DNA alone has a wobble of about 30%. There is chromosome structure which we only begin to understand; there is multiplicity of genes within chromosomes, within genomes and polyploid nuclei. The Hardy-Weinberg Law is the only wobble considered by classical genetics, and every population geneticist knows of the complications that arise from this simple, special case. As for proteins; several amino acids can be exchanged for each one present in almost any segment of polypeptides without effect on the stability and dynamic performance of the respective enzyme[16,17]; there are dozens of proteins that cooperate within a single physiological function (respiration, muscel contraction, etc.), each of which may affect this function. And still, we find ourselves on the cellular level only; and while selection via sexual reproduction always descends to this cellular level, fitness for survival does not. One individual within a given population survives better because it escaped predator attack, the other because its immune reaction overcame infection, a third because of optimal maternal care etc. ... etc. ... Biophysically, all these wobbles have the same results: many causes lead to the same pattern, hence, the impossibility of selecting for a specific cause via this pattern. In concrete genetic terms this means that innumerable allelic combinations permit similar phase patterns of growth and similar values of selective fitness. Therefore, it is highly improbable that sequential selection of individual mutations in the base sequence of DNA is the cause of specific phylogenetic differentiation on the level of the anatomy, morphology and physiology of whole organisms.

Only by explicit definition of the relevant hierarchical levels of structure and function can we arrive at a causal explanation of higher evolution.

Separation of causative and permissive levels of structure permits already the following, general conclusions: *only* those variations on lower levels of structure that permit successful function on higher levels are tolerated within the system; *all* variations on lower levels that permit function of the observed higher level are presumably tolerated within the system. In other words; one would naturally expect genetic polymorphism, and one would puzzle, and search for specific answers, where it is absent (genetic repair)[18-21]. By this, selection is translated into mechanical terms: successful function on a specific, hierarchical level of organization; success meaning that this function *permits* indefinite reproduction of the units enganged in the respective function (note that it does not *cause* indefinite reproduction).

3. Continuous and discrete

Growth may be continuous or discrete. The increase of the circumference of a cell after mitosis, or of human height after birth, would commonly be seen as continuous functions, while replication of chromosomes is regarded as a discrete event.

Admitting that observation of dynamic processes in space is the only basis for a concept of order in time, we find that the distinction between these 2 qualities is conditioned by the process of observation. As examples we may choose 2 historical time-measuring devices, the pendulum and the hour glass (fig. 1). Each period of the pendulum may be regarded as a discrete event (specifically if it is translated into steps

of the minute hand), yet the movement is continuous and may be pictured as a wave-like function. The movement of the sand from the upper container in the hourglass to the lower may be classified as continuous flow; yet, if we constrict the passage sufficiently and work with magnifying glass and cinematography, we may count grain by grain. Turning the hourglass, once the upper container is empty, is a single, discrete event, yet fast rotation with a motor would be a continuous function. Thus, we find that one and the same 'machine' may be classified as discrete or continuous depending on 1. the hierarchical level singled out for observation; and 2. the phase relations between the observing mechanism and the observed event. Objective distinction between the 2 physical properties 'continuous' and 'discrete' must exclude interference between observer and observed system. Hence, I arrived at the following definitions, which make no claim to ultimate, transcendental bruth, but result in empirical practicality:

Definition: A process or structure is considered discrete or dis-continuous if the relation between the number of sub-units or periods and the respective super-unit is expressible in small integer numbers; inversely, the system is considered continuous, if this relation is a large, and not necessarily an integer number. In between lies a zone of mechanical malfunction or static instability the range of which is specific for each system (fig. 4). A car with 11.63 wheels or an animal with 7.58 legs is non-functional; we can look at transparencies at frequencies of 1–2 per min or 1500–1800 per min (film), but would leave the room with a headache at 70 per min.

From these considerations we can conclude the following: All variation on hierarchically inferior levels that push a given system into this twilight zone of malfunction cannot persist (i.e. cannot be reproduced indefinitely). Furthermore, if, in the course of evolution, organisms changed from continuous to discontinuous functions, these transitions represent jumps, because continuous increase or decrease of functional elements would lead a system through non-functional states. Thus, the tetrapod condition of vertebrates appeared almost at once; the most successful groups of arthropods confine the number of their locomotory appendages to below 10; moreover, it is possible to derive simple rules for fusion, deletion and branching of segments[14]. On the cellular level, flagellates have 2, 4, and only exceptionally more flagellae, while ciliates carry hundreds. Even the flowering plants, although sessile, settled the number of their flowering parts (carpels, stamens, petals) preferably at 2, 3, 4, 5, and 6, or they carry a large, more-or-less indefinite number (Nymphaceae, Magnoliaceae). These general trends are broken by many exceptions, but, as mentioned above, the non-functional zone is specific for any given system engaged in evolutionary change.

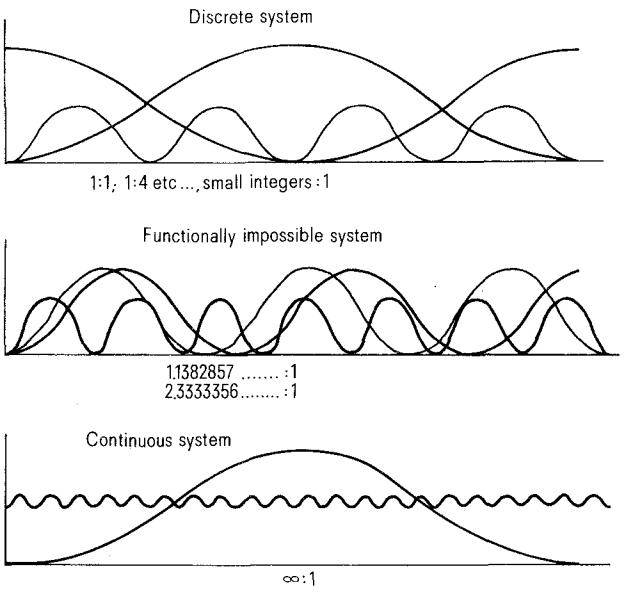

Figure 4. Definitions of the concepts 'discrete' and 'continuous'.

Threshold functions: The necessity of efficient, mechanical function on discrete levels of organization implies that morphogenesis of the constituent units is an 'all-or-none process': they are either formed 'normally' or the organism is non-viable; the morphogenetic process cannot be sensitive to minor variations in genotype and environment, there is no continuous response to continuously changing parameters. This suggests that threshold values of continuous parameters, such as concentrations (hormones, gradients, 'organizers', etc.), ionic strength, pH, pressure and temperature, etc., trigger morphogenetic events on discontinuous levels of organization. Accumulation of large numbers of sub-units (multiplication of cilia, of segments, etc.) may lead to the transition from discrete to continuous organization, while threshold values may switch a system to discontinuous organization, as for instance fusion of segments to a super-unit (for examples, see Walker[14]), or differentiation between homologous segments etc.

4. Conclusions

The model of the organic hierarchy allows for the following general conclusions:

The necessity of successful mechanical function on higher levels with discrete organization means, that all variation of the immensely complex biochemical network of any given organism can lead at best to very few, basic structural phenotypes on the organismic level (especially patterns of segmentation).

Once a specific set of alleles guarantees a vital threshold function, all other *allelic variation* that would also lead to above-threshold-value, is *neutral* with regard to the respective phenotype.

If the environment induces a particular phenotype[14,22,23], all *genetic variation* that would also lead to

this phenotype, is *neutral* with regard to this phenotype.

No matter whether genetic and/or environmental changes induced the genesis of a new phenotype, neutral mutations will tend to accumulate (provided that the new genotype and environment persist). Hence, the probability of reversal declines in the course of time. This decline is positively related to the range of overall wobble within the hierarchy. The more allelic combinations there are that lead to similar phenotype and to similar fitness values, the faster their accumulation by mutation. Logically, then, we should conclude that the higher the hierarchical organization, the faster is phylogenetic fixation of its morphotype, and the narrower is this morphotype's somatic plasticity vis-à-vis environmental parameters. This conclusion is largely confirmed if we compare 'lower' and 'higher' organisms. This new category of complex-irreversibility gives neutral alleles an important role in evolution: genetic stabilization of phylogenetic change, and in the long run, perhaps, extinction from loss of adaptive plasticity.

In short then: In higher evolution, phase-shift of reproductive rates of units between and within hierarchical levels of organization *cause* phylogenetic change; chemical plasticity of proteins vis-à-vis environmental and genetic variation *permits* phylogenetic change; accumulation of neutral alleles *causes* stabilization of phylogenetic change. Selected is everything that is not rejected. This is not a dogma. Perhaps some day we may discover a specific super-allele that selects against all others and causes a taxonomic change. We will then have found the exception that confirms the rule.

1 Acknowledgment. I thank Dr P. Henderson for much stimulating discussion and for critically reading the manuscript.

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Genetic polymorphism: from electrophoresis to DNA sequences[1]

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Summary. Recent studies indicate that the amount of protein variation undetected by electrophoresis may be reasonably small. Nevertheless, at the protein level, a typical sexually-reproducing organism may be heterozygous at 20 or more percent of the gene loci. Although the evidence is limited, it appears that at the level of the DNA nucleotide sequence every individual is heterozygous at every locus – if introns as well as exons are taken into account. The evidence available does not support the hypothesis that, at least at the protein level, the variation is adaptively neutral.