ANALOGY AS A SOURCE OF KNOWLEDGE

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by

Konrad Z. Lorenz

Austrian Academy of Sciences
Institute of Comparative Behaviour Research, Altenberg, Austria

1. The Concept of Analogy

In the course of evolution it constantly happens that, independently of each other, two different forms of life take similar, parallel paths in adapting themselves to the same external circumstances. Practically all animals which move fast in a homogeneous medium have found means of giving their body a streamlined shape, thereby reducing friction to a minium. The "invention" of concentrating light on a tissue sensitive to it by means of a diaphanous lens has been made independently at least four times by different phyla of animals; and in two of these, in the cephalopods and in the vertebrates, this kind of "eye" has evolved into the true, image-projecting camera through which we ourselves are able to see the world.

Thanks to old discoveries by Charles Darwin and very recent ones by biochemists, we have a fairly sound knowledge of the processes which, in the course of evolution, achieve these marvellous structures. The student of evolution has good reason to assume that the abundance of different bodily structures which, by their wonderful expediency, make life possible for such amazingly different creatures under such amazingly different conditions, all owe their existence to these processes which we are wont to subsume under the concept of adaptation. This assumption, whose correctness I do not propose to discuss here, forms the basis of the reasoning which the evolutionist applies to the phenomenon of analogy.

2. Deducing comparable survival value from similarity of form

Whenever we find, in two forms of life that are unrelated to each other, a similarity of form or of behaviour patterns which relates to more than a few minor details, we assume it to be caused by parallel adaptation to the same life-preserving function. The improbability of coincidental similarity is proportional to the number of independent traits of similarity, and is, for n such characters, equal to 2^{n-1}. If we find, in a swift and in an airplane, or in a shark, or a dolphin and in a torpedeo, the striking resemblances illustrated in Fig. 1, we can safely assume that in the organisms as well as in the man-made machines, the need to reduce friction has led to parallel adaptations. Though the independent points of similarity are, in these cases, not very many,

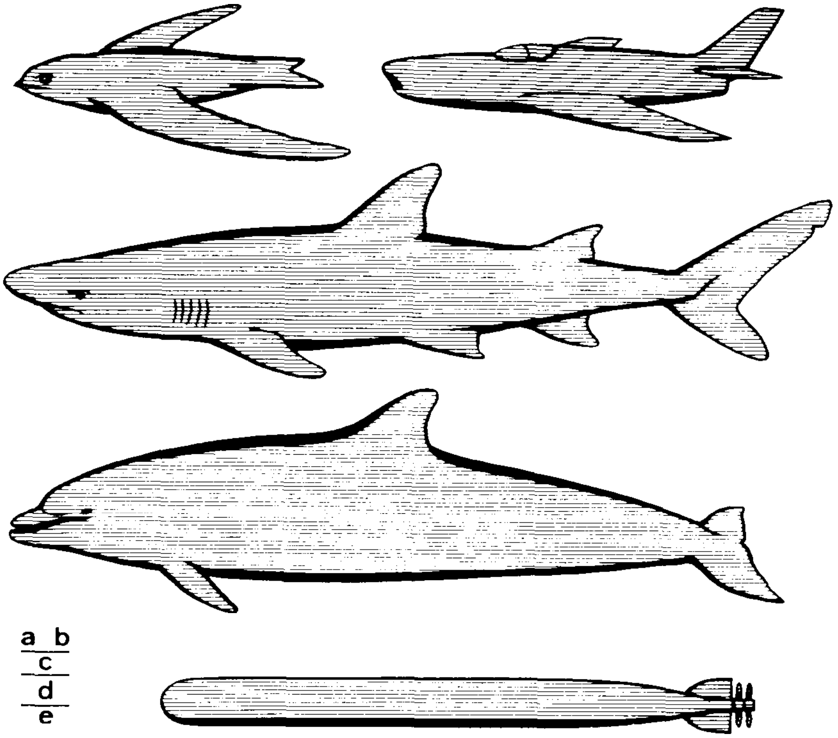

Fig. 1. Analogy of form due to adaptation to an identical function. Streamlining in a) a swift, b) a fighter plane, c) a shark, d) a dolphin, e) a torpedo.

it is still a safe guess that any organism or vehicle possessing them is adapted to fast motion;

There are conformities which concern an incomparably greater number of independent details. Fig. 2 shows cross sections through the eyes of a vertebrate and a cephalopod. In both cases there is a lens, a retina connected by nerves with the brain, a muscle moving the lens in order to focus, a contractile iris acting as a diaphragm, a diaphanous cornea in front of the camera and a layer of pigmented cells shielding it from behind - as well as many other matching details. If a zoologist who knew nothing whatever of the existence of cephalopods were examining such an eye for the very first time, he would conclude without further ado that it was indeed a light-perceiving organ. He would not even need to observe a live octopus to know this much with certainty.

3. The allegation of "false analogy'

Ethologists are often accused of drawing *false* analogies between animal and human behaviour. However, no such thing as a *false* analogy exists: an analogy can be more or less detailed and hence more or less informative. Assiduously searching for a really false analog), I found a couple of technological

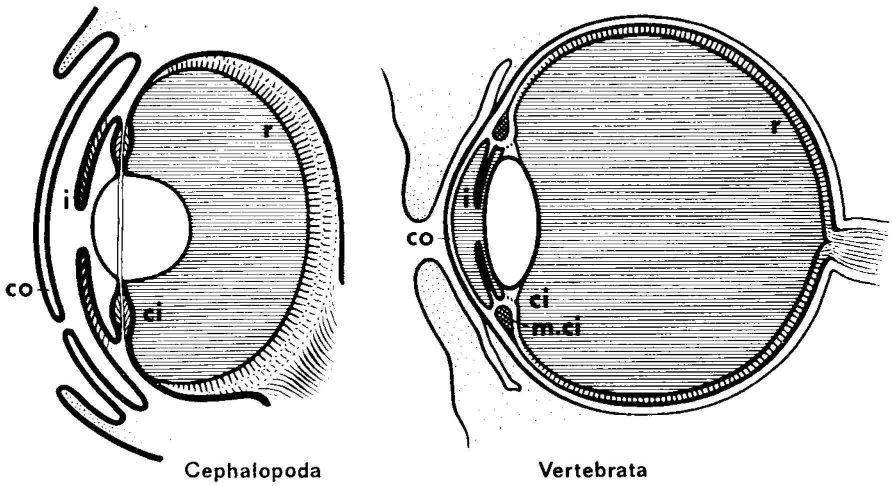

Fig. 2. Detailed analogy in two independently evolved light-perceiving organs, left the eye of an octopus, right of a man, co Cornea, ci Corpus ciliare, m.ci musculus ciliaris, i iris, r retina.

examples within my own experience. Once I mistook a mill for a sternwheel steamer. A vessel was anchored on the banks of the Danube near Budapest. It had a little smoking funnel and at its stern an enormous slowly-turning paddle-wheel. Another time, I mistook a small electric power plant, consisting of a two-stroke engine and a dynamo, for a compressor. The only biological example that I could find concerned a luminescent organ of a pelagic gastropod, which was mistaken for an eye, because it had an epidermal lens and, behind this, a high cylindrical epithelium connected with the brain by a nerve Even in these examples, the analogy was false only in respect of the direction in which energy was transmitted.

4. The concept of homology

There is, in my opinion, only one possibility of an error that might conceivably be described as the "drawing of a false analogy" and that is mistaking an *homology* for an analogy. An homology can be defined as any resemblance between two species that can be explained by their common descent from an ancestor possessing the character in which they are similar to each other. Strictly speaking, the term homologous can only be applied to characters and not to organs. Fig. 3 shows the forelimbs of a number of tetrapod vertebrates intentionally chosen to illustrate the extreme variety of uses to which a front leg can be put and the evolutional changes it can undergo in the service of these different functions. Notwithstanding the dissimilarities of these functions and of their respective requirements, all these members are built on the same basic plan and consist of comparable elements, such as bones, muscles, nerves. The very dissimilarity of their functions makes it extremely improbable that

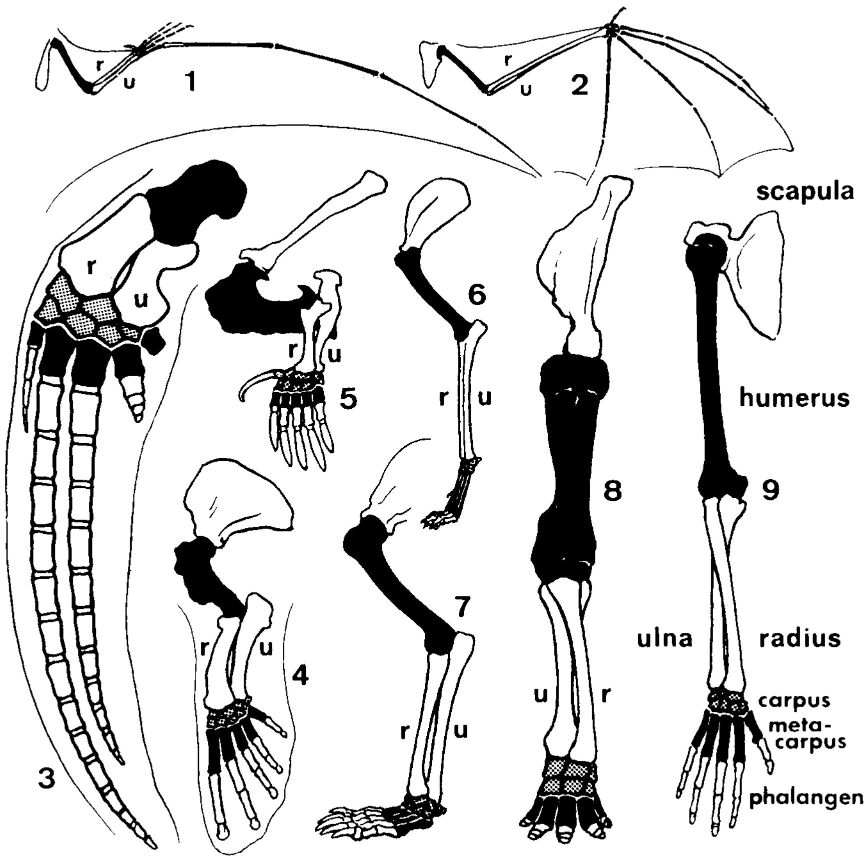

Fig. 3. Anterior limbs of vertebrates. 1. Jurassic flying reptile. 2. Bat. 3. Whale. 4. Sea Lion. 5. Mole. 6. Dog. 7. Bear. 8. Elephant. 9. Man. The humerus and the metacarpal bones are tinged in black, the carpal bone grey

the manifold resemblances of their forms could be due to parallel adaptation, in other words to analogy.

As a pupil of the comparative anatomist and embryologist Ferdinand Hochstetter, I had the benefit of a very thorough instruction in the methodological procedure of distinguishing similarities caused by common descent from those due to parallel adaptation. In fact, the making of this distinction forms a great part of the comparative evolutionist's daily work. Perhaps I should mention here that this procedure has led me to the discovery which I personally consider to be my own most important contribution to science. Knowing animal behaviour as I did, and being instructed in the methods of phylogenetic comparison as I was, I could not fail to discover that the very same methods of comparison, the same concepts of analogy and homology are as applicable to characters of behaviour as they are in those of morphology. This discovery is implicitly contained in the works of Charles Otis Whitman and of Oskar Heinroth; it is only its explicit formulation and the realization of its far-reaching inferences to which I can lay claim. A great part of my life's work has

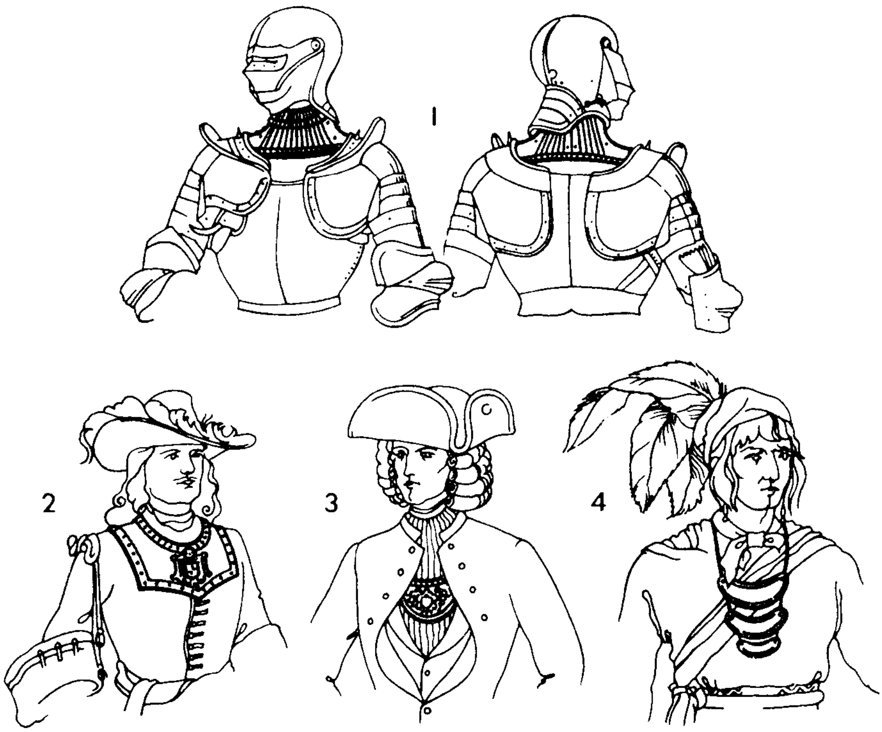

Fig. 4. Change of function in a pieve of medieval armour which, losing its protective function, becomes a status symbol of officers.

consisted in tracing the phylogeny of behaviour by disentangling the effects of homology and of parallel evolution. Full recognition of the fact that behaviour patterns can be hereditary and species-specific to the point of being homologizable was impeded by resistance from certain schools of thought, and my extensive paper on homologous motor patterns in *Anatidae* was necessary to make my point.

5. Cultural homology

Much later in life I realized that, in the development of human cultures, the interaction between historically-induced similarities and resemblances caused by parallel evolution - in other words between homologies and analogies - was very much the same as in the phylogeny of species and that it posed very much the same problems. I shall have occasion to refer to these later on; here I want to illustrate the existence of cultural homology. Fig. 4 illustrates the cultural changes by which the piece of medieval armour that was originally designed to protect throat and chest was gradually turned, by a change of function, into a status symbol. Otto Koenig, in his book *Kulturethologie*, has adduced many other examples of persistent historically-induced similarity of characters to which the adjective "homologous" can legitimately be applied.

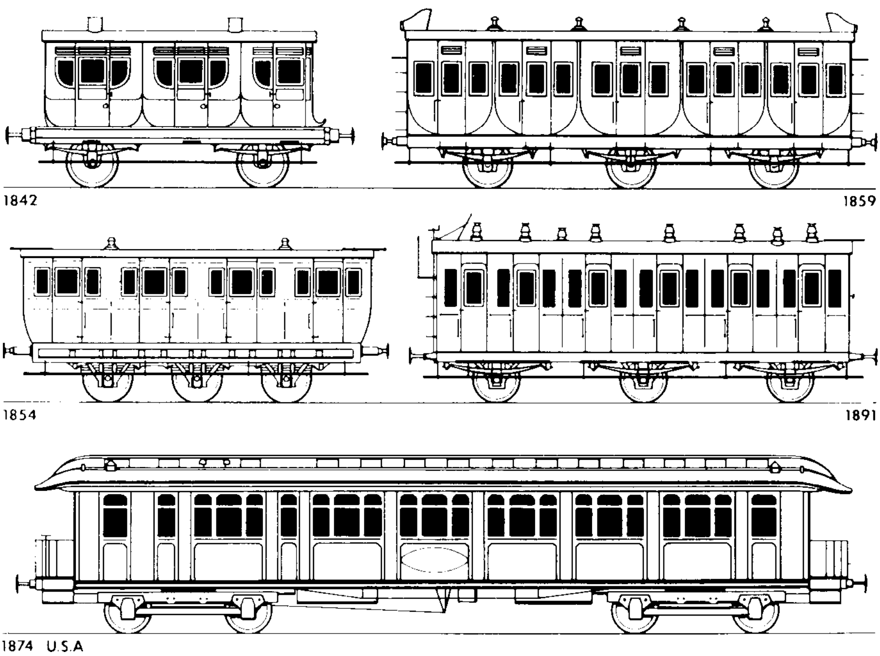

Fig. 5. Homology of technical products. Characters traceable to the ancestor, the horse-drawn coach persists, against the interests of technical progress, in railway carriages.

Ritualization and symbolisms play a large role in traditional clothing and particularly in military uniforms in their historical changes, so that the appearance of historically-retained similarities is, perhaps, not very surprising. It is, however, surprising that the same retention of historical features, not only independently of function, but in clear defiance of it, is observable even in that part of human culture which one would suppose to be free of symbolism, ritualization and sentimental conservativism, namely in technology. Fig. 5 illustrates the development of the railway carriage. The ancestral form of the horse-drawn coach stubbornly persists, despite the very considerable difficulties which it entails, such as the necessity of constructing a runningboard all along the train, on which the conductor had to climb along, from compartment to compartment, exposed to the inclemency of the weather and to the obvious danger of falling off. The advantages of the alternative solution of building a longitudinal corridor within the carriage are so obvious that they serve as a demonstration of the amazing power exerted by the factors tending to preserve historical features in defiance of expediency.

The existence of these cultural homologies is of high theoretical importance, as it proves that, in the passing-on of cultural information from one generation to the next, processes are at work which are entirely independent of rational considerations and which, in many respects, are functionally analogous to the factors maintaining invariance in genetical inheritance.

6. Deducing function from behavioural analogies

Let me now speak of the value of analogies in the study of behaviour. Not being vitalists, we hold that any regularly observable pattern of behaviour which, with equal regularity, achieves survival value is the function of a sensory and nervous mechanism evolved by the species in the service of that particular function. Necessarily, the structures underlying such a function must be very complicated, and the more complicated they are, the less likely it is, as we already know, that two unrelated forms of life should, by sheer coincidence, have happened to evolve behaviour patterns which resemble each other in a great many independent characters.

A striking example of two complicated sets of behaviour patterns evolving independently in unrelated species, yet in such a manner as to produce a great number of indubitable analogies is furnished by the behaviour of human beings and of geese when they fall in love and when they are jealous. Time and again I have been accused of uncritical anthropomorphism when describing, in some detail, this behaviour of birds and people. Psychologists have protested that it is misleading to use terms like falling in love, marrying or being jealous when speaking of animals. I shall proceed to justify the use of these purely functional concepts. In order to assess correctly the vast improbability of two complicated behaviour patterns in two unrelated species being similar to each other in so many independent points, one must envisage the complication of the underlying physiological organization. Consider the minimum degree of complication which even a man-made electronic model would have to possess in order to simulate, in the simplest possible manner, the behaviour patterns here under discussion. Imagine an apparatus, A, which is in communication with another one, B, and keeps on continuously checking whether apparatus B gets into communication with a third apparatus C, and which furthermore, on finding that this is indeed the case, does its utmost to interrupt this communication. If one tries to build models simulating these activities, for example in the manner in which Grey-Walter's famous electronic tortoises are built, one soon realizes that the minimum complication of such a system far surpasses that of a mere eye.

The conclusion to be drawn from this reasoning is as simple as it is important. Since we know that the behaviour patterns of geese and men cannot possibly be homologous - the last common ancestors of birds and mammals were lowest reptiles with minute brains and certainly incapable of any complicated social behaviour - and since we know that the improbability of coincidental similarity can only be expressed in astronomical numbers, we *know for certain* that it was a more or less identical survival value which caused jealousy behaviour to evolve in birds as well as in man.

This, however, is *all* that the analogy is able to tell us. It does not tell us wherein this survival value lies - though we can hope to ascertain this by observations and experiments on geese. It does not tell us anything about the physiological mechanisms bringing about jealousy behaviour in the two species; they may well be quite different in each case. Streamlining is achieved in the shark by the shape of the musculature, in the dolphin by a thick layer of, blubber, and in the torpedo by welded steel plates. By the same token, jealousy may be - and probably is - caused by an inherited and genetically fixed programme in geese, while it might be determined by cultural tradition in man - though I do not think it is, at least not entirely.

Limited though the knowledge derived from this kind of analogy may be, its importance is considerable. In the complicated interaction of human social behaviour, there is much that does not have any survival value and never had any. So it is of consequence to know that a certain recognizable pattern of behaviour does, or at least once did, possess a survival value for the species, in other words, that it is *not pathological*. Our chances of finding out wherein the survival value of the behaviour pattern lies are vastly increased by finding the pattern in an animal on which we can experiment.

When we speak of falling in love, of friendship, personal enmity or jealousy in these or other animals, we are *not* guilty of anthropomorphism. These terms refer to functionally-determined concepts, just as do the terms legs, wings, eyes and the names used for other bodily structures that have evolved independently in different phyla or animals. No one uses quotation marks when speaking or writing about the eyes or the legs of an insect or a crab, nor do we when discussing analogous behaviour patterns.

However, in using these different kinds of terms, we must be very clear as to whether the word we use at a given moment refers to a concept based on functional analogy or to one based on homology, e.g. on common phyletic origin. The word "leg" or "wing" may have the connotation of the first kind of concept in one case and of the second in another. Also, there is the third possibility of a word connoting the concept of physiological, causal identity. These three kinds of conceptualization may coincide or they may not. To make a clear distinction between them is particularly important when one is speaking of behaviour. A homologous behaviour pattern can retain its ancestral form and function in two descendants, and yet become physiologically different. The rhythmical beat of the umbrella is caused by ondogenous stimulus generation in many hydrozoa and in larva *(Ephyrae)* in other medusae. In adult *Scyphomedusae*, however, it is caused by reflexes released through the mechanism of the so-called marginal bodies. A homologous motor pattern may retain its original physiological causation as well as its external forms, yet undergo an entire change of function. The motor pattern of "inciting" common to the females of most *Anatidae* is derived from a threatening movement and has the primary function of causing the male to attack the adversary indicated by the female's threat. It has entirely lost this function in some species, for instance in the Golden-eyes, in which it has become a pure courtship movement of the female. Two non-homologous motor patterns of two related species may, by a change of function, be pressed into the service of the same survival value. The pre-flight movement of ducks is derived from an intention movement of flying, an upward thrust of head and neck, while the corresponding signal of geese is derived from a displacement shaking of the head. When we speak of "pre-flight movements of *Anatidae*" we form a functional concept embracing both. These examples are sufficient to demonstrate the importance of keeping functional, phylogenetical and physiological conceptualizations clearly apart. Ethologists are not guilty of "reifications" or of illegitimate anticipations of physiological explanations when they form concepts that are only functionally defined - like, for instance, the concept of the IRM, the innate releasing mechanism. They are, in fact, deeply aware that this function may be performed by the sensory organ itself - as in the cricket - or by a complicated organization of the retina - as in the frog - or by the highest and most complicated processes within the central nervous system.

DEDUCING THE EXISTENCE OF PHYSIOLOGICAL MECHANISMS FROM KNOWN ANALOGOUS FUNCTIONS

Recognizing analogies can become an important source of knowledge in quite another way. We can assume with certainty that, for instance, the functions of respiration, of food intake, of excretion, of propagation, etc., must somehow be performed by any living organism. In examining an unknown living system, we are, therefore, justified in *searching* for organs serving functions which we know to be indispensable. We are surprised if we miss some of them, for instance the respiratory tract in some small salamanders which breathe exclusively through their skin.

A human culture is a living system. Though it is one of the highest level of integration, its continuance is nevertheless dependent on all the indispensable functions mentioned above. The thought obtrudes itself that there is one of these necessary functions which is insufficient in our present culture, that of *excretion.* Human culture, after enveloping and filling the whole globe, is in danger of being killed by its own excretion, of dying from an illness closely analogous to uraemia. Humanity will be forced to invent some sort of planetary kidney - or it will die from its own waste products.

There are other functions that are equally indispensable to the survival of all living systems, ranging from bacteria to cultures. In any of these systems, adaptation has been achieved by the process, already mentioned, which hinges on the *gaining of information* by means of genetic change and natural selection, as well as on the storing of knowledge in the code of the chain molecules in the genome.

This storing, like *any* retention of information, of knowledge, is achieved by the formation of *structure.* Not only in the little double helix, but also in the programming of the human brain, in writing, or any other form of "memory bank", knowledge is laid down in structures.

The indispensable supporting and retaining function of structure always has to be paid for by a "stiffening", in other words, by the sacrifice of certain *degrees of freedom.* The structure of our skeleton provides an example; a worm can bend its body at any point, whereas we can flex our limbs only where joints are provided; but we can stand upright and the worm cannot.

All the adaptedness of living systems is based on knowledge laid down in structure; structure means *static* adapted*ness*, as opposed to the dynamic process of adaptation. Hence, new adaptation unconditionally presupposes a *dismantling* of some structures. The gaining of new information inexorably demands the breaking down of some previous knowledge which, up to that moment, had appeared to be final.

The dynamics of these two antagonistic functions are universally common to all living systems. Always, a harmonious equilibrium must be sustained between, on the one hand, the factors maintaining the necessary degree of *invariance* and, on the other, the factors which tend to break up firm structures and thereby create the degree of *variability* which is the prerequisite of all further gaining of information, in other words, of all new adaptation.

All this is obviously true of human culture as well as of any other living system whose lifespan exceeds that of the individual, e.g. of any species of bacteria, plants or animals. It is, therefore, legitimate to search for the mechanisms which, in their harmonious antagonism of preserving and dismantling structures, achieve the task of keeping a culture adapted to its ever-changing environment. In my latest book Die Rückseite des Spiegels, I have tried to demonstrate these two antagonistic sets of mechanisms in human culture.

The preservation of the necessary invariance is achieved by procedures curiously reminiscent of genetic inheritance. In much the same manner as the new nucleotids are arranged along the old half of a double helix, so as to produce a *copy* of it, the invariant structures of a culture are passed on, from one generation to the next, by a process *in which the young generation makes a copy* of the cultural knowledge possessed by the old. Sheer imitation, respect for a father-figure, identification with it, force of habit, love of old ritualized customs and, last not least, the conservativism of "magical thinking" and superstition - which as we have seen influences even the construction of railway carriages - contributes to invest cultural tradition with that degree of invariance which is necessary *to make it inheritable at all.*

Opposed to these invariance-preserving mechanisms, there is the specifically human urge to curiosity and freedom of thought which with some of us, persists until senescence puts a stop to it. However, the age of puberty is typically the phase in our ontogeny during which we tend to rebel against tradition, to doubt the wisdom of traditional knowledge and to cast about for new causes to embrace, for new ideals.

In a paper which I read a few years ago - at a Nobel symposium on "The Place of Value in a World of Facts" - I tried to analyse certain malfunctions of the antagonistic mechanisms and the dangers of an enmity between the generations arising from these disturbances. I tried to convince my audience that the question whether conservativism is "good" or "bad", or whether the rebellion of youth is "good" or "bad", is just as inane as the question whether some endocrine function, for instance that of the thyroid gland, is "good" or "bad". Excesses as well as deficiency of any such function cause illness. Excess of thyroid function causes Basedow's disease, deficiency myxoedema. Excess of conservativism produces living fossils which will not go on living for long, and excess of variability results in the appearance of monsters which are not viable at all.

Between the conservative representatives of the "establishment" on the one hand and rebelling youth on the other, there has arisen a certain enmity which makes it difficult for each of the antagonists to recognize the fact that the endeavours of *both* are *equally* indispensable for the survival of our culture. If and when this enmity escalates into actual *hate*, the antagonists cease to interact in the normal way and begin to treat each other as different, hostile cultures; in fact they begin to indulge in activities closely akin to tribal warfare. This represents a great danger to our culture, inasmuch as it may result in a complete disruption of its traditions.