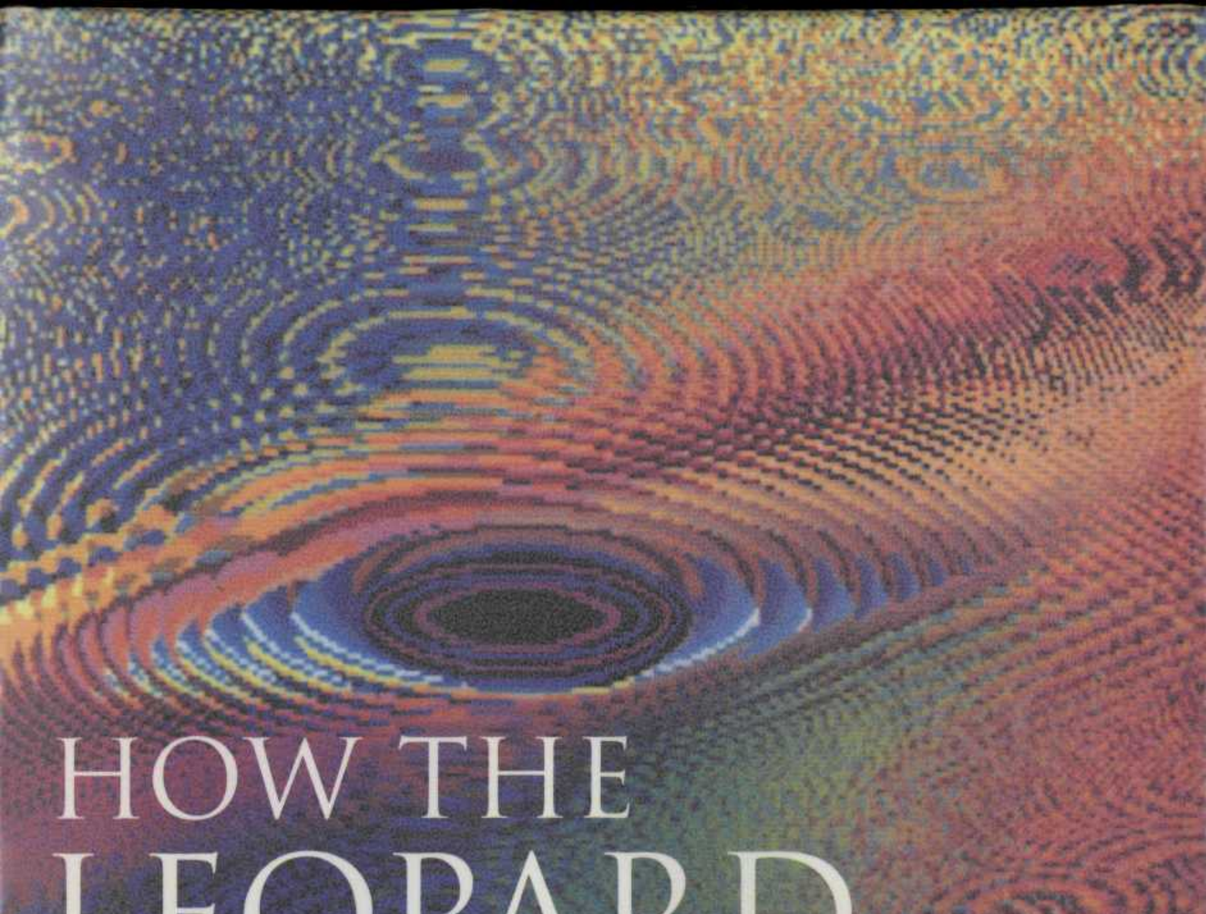

HOW THE LEOPARD CHANGED ITS SPOTS

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A summary of the argument

Scientific theories develop out of choices and assumptions that are neither arbitrary nor inevitable. Darwin made particular assumptions about the properties of organisms and their evolution that have led to one of the most successful theories ever to have emerged in science. He accepted that the major phenomenon of life that needs to be accounted for is the adaptation of organisms to their habitats, and he believed that this could be explained in terms of random hereditary variations among the members of a species and natural selection of the better variants over long periods of evolutionary time. This has become the basis for explaining all aspects of life on earth, or elsewhere. No aspect of human life is untouched by Darwin's theory of evolution, modified in various ways to apply to economics and politics, to the explanation of the origins and the significance of art, and even to the history of ideas themselves.

However, all theories carry with them a particular viewpoint, a way of seeing phenomena that produces sharp focus on certain aspects of reality and blurred vision elsewhere. A striking paradox that has emerged from Darwin's way of approaching biological questions is that organisms, which he took to be primary examples of living nature, have faded away to the point where they no longer exist as fundamental and irreducible units of life. Organisms have been replaced by genes and their products as the basic elements of biological reality. This may seem to fly in the face of all common sense, but stranger things have happened in the name of science. What's more, there is no lack of highly persuasive books whose objective is to demonstrate why organisms are not what they seem to be – integrated entities with lives and natures of their own – but complex molecular machines controlled by the genes carried within them, bearers of the historical record of the species to which the organism belongs. Though this is certainly not what he anticipated, this is in fact the sharp focus that has developed from Darwin's assumptions about the nature of life, and there is no denying the remarkable insights that have accompanied this illumination of the molecular level of organisms.

There is always a price to be paid for excessive preoccupation with one aspect of reality. Modern biology has come to occupy an extreme position in the spectrum of the sciences, dominated by historical explanations in terms of the evolutionary adventures of genes. Physics, on the other hand, has developed explanations of different levels of reality, microscopic and macroscopic, in terms of theories appropriate to these levels, such as quantum mechanics for the behaviour of microscopic particles (photons, electrons, quarks, etc.) and hydrodynamics for the behaviour of macroscopic liquids. It is the absence of any theory of organisms as distinctive entities in their own right, with a characteristic type of dynamic order and organization, that has resulted in their disappearance from the basic conceptual structure of modern biology. They have succumbed to the onslaught of an overwhelming molecular reductionism.

Here we face another curious consequence of Darwin's way of looking at life: despite the power of molecular genetics to reveal the hereditary essences of organisms, the large-scale aspects of evolution remain unexplained, including the origin of species. There is 'no clear evidence ... for the gradual emergence of any evolutionary novelty' says Ernst Mayr, one of the most eminent of contemporary evolutionary biologists. New types of organism simply appear upon the evolutionary scene, persist for various periods of time, and then become extinct. So Darwin's assumption that the tree of life is a consequence of the gradual accumulation of small hereditary differences appears to be without significant support. Some other process is responsible for the emergent properties of life, those distinctive features that separate one group of organisms from another, such as fishes and amphibians, worms and insects, horsetails and grasses. Clearly something is missing from biology. It appears that Darwin's theory works for the small-scale aspects of evolution: it can explain the variations and the adaptations within species that produce fine-tuning of varieties to different habitats. The large-scale differences of form between types of organism that are the foundation of biological classification systems seem to require a principle other than natural selection operating on small variations, some process that gives rise to distinctly different forms of organism. This is the problem of emergent order in evolution, the origins of novel structures in organisms that has always been a primary interest in biology.

It is here that new theories, themselves recently emerged within mathematics and physics, offer significant insights into the origins of biological order and form. Whereas physicists have traditionally dealt with 'simple' systems in the sense that they are made up of few *types* of component, and observed macroscopic or large-scale order is then explained in terms of uniform interactions between these components, biologists deal with systems (cells, organisms) that are hideously complex, with thousands of different types of gene and molecule all interacting in different ways. Or so it seems at the molecular level. However, what is being recognized within the 'sciences of complexity', as studies of these highly diverse systems are called, is that there *are* characteristic types of order that emerge from the interactions of many different components. And the reason is not unlike what happens in 'simple' physical systems.

Despite the extreme diversity of genes and molecules in organisms, their interactions are limited so that distinctive types of order arise, especially in relation to the large-scale aspects of structure or morphology, and the patterns in time that constitute organismic behaviour. A particularly striking property of these complex systems is that even chaotic behaviour at one level of activity, molecules or cells or organisms, can give rise to distinctive order at the next level, morphology and behaviour. This has resulted in one of the primary recurring themes of complex studies: order emerges out of chaos. The source of large-scale order in biology may therefore be located in a distinctive type of complexity of the living state that is often described in terms of the computational capacity of the interacting components rather than their dynamic behaviour. These terms, computational and dynamic, actually reflect different emphases and are not in conflict with one another. What has developed from the widespread use of computers to explore the dynamic potential of interacting systems that can process information, such as biological molecules, cells, or organisms, is a new theory of dynamical systems collectively referred to as the sciences of complexity, from which have developed significant branches such as artificial life.

In this book I explore the consequences of these ideas as they apply to our understanding of the emergence of biological forms in evolution, particularly the origin and nature of the morphological characteristics that distinguish different types of organism. These questions overlap with those addressed by Darwin but they focus on the large-scale or global aspects of biological form rather than on small-scale, local adaptations. As a result, there is no necessary conflict between the approaches, nor with the insights of modern biology into the genetic and molecular levels of organisms. These contribute to the construction of dynamical theories from which emerge higher-level properties of biological form and the integrated behaviour of organisms. Conflict arises only when there is confusion about what constitutes biological 'reality'. I take the position that organisms are as real, as fundamental, as irreducible, as the molecules out of which they are made. They are a separate and distinct level of emergent biological order, and the one to which we most immediately relate since we ourselves are organisms.

The recognition of the fundamental nature of organisms, connecting directly with our own natures as irreducible beings, has significant consequences regarding our attitude to the living realm. It is here that another aspect of scientific theories comes to the fore, one that is often regarded as irrelevant or secondary to the 'facts' that science uncovers. Darwinism, like all theories, has distinct metaphorical associations that are familiar from the use of descriptive terms such as survival of the fittest, competitive interactions between species, selfish genes, survival strategies, even war games with hawk and dove strategies. Such metaphors are extremely important. They give meaning to scientific theories, and they encourage particular attitudes to the processes described: in the case of Darwinism, to the nature of the evolutionary process as one predominantly driven by competition, survival, and selfishness. This makes sense to us in terms of our experience of our own culture and its values. Both culture and nature then become rooted in similar ways of seeing the world, which are shaped at a deeper level than metaphor by cultural myths, from which the metaphors arise. The consequences of this perspective have emerged particularly clearly in this century, especially in the view of species as arbitrary collections of genes that have passed the survival test. The criterion of value here is purely functional: species either work or they don't. They have no intrinsic value.

I shall argue that this view of species arises from a limited and complexity lead to the construction of a dynamic theory of inadequate view of the nature of organisms. The sciences of organisms as the primary source of the emergent properties of life that have been revealed in evolution. These properties are generated during the process known as morphogenesis, the development of the complex form of the adult organism from simple beginnings such as an egg or a bud. During morphogenesis, emergent order is generated by distinctive types of dynamic process in which genes play a significant but limited role. Morphogenesis is the source of emergent evolutionary properties, and it is the absence of a theory of organisms that includes this basic generative process that has resulted in both the disappearance of organisms from Darwinism and the failure to account for the origin of the emergent characteristics that identify species.

Many people have recognized this limitation of Darwin's vision, and my own arguments are utterly dependent upon their demonstration of the path to a more balanced biology. Primary among these is the towering achievement of D'Arcy Thompson in his volumes *On Growth and Form* (1917) in which he single-handedly defines the problem of biological form in mathematical terms and re-establishes the organism as the dynamic vehicle of biological emergence. Once this is included in an extended view of the living process, the focus shifts from inheritance and natural selection to creative emergence as the central quality of the evolutionary process. And, since organisms are primary loci of this distinctive quality of life, they become again the fundamental units of life, as they were for Darwin. Inheritance and natural selection continue to play significant roles in this expanded biology, but they become parts of a more comprehensive dynamical theory of life which is focused on the dynamics of emergent processes.

The consequences of this altered perspective are considerable, particularly in relation to the status of organisms, their creative potential, and the qualities of life. Organisms cease to be simply survival machines and assume intrinsic value, having worth in and of themselves, like works of art. Such a realization arises from an altered understanding of the nature of organisms as centres of autonomous action and creativity, connected with a causal agency that cannot be described as mechanical. It is relational order *between* components that matters more than material composition in living processes, so that emergent qualities predominate over quantities. This consequence extends to social structure, where relationships, creativity and values are of primary significance. As a result, values enter fundamentally into the appreciation of the nature of life and biology takes on the properties of a science of qualities, the substance of Chapter 7 in this book. This is not in conflict with the predominant science – of quantities – but it does have a different focus and emphasis.

Darwinism sees the living process in terms that emphasize competition, inheritance, selfishness, and survival as the driving forces of evolution. These are certainly aspects of the remarkable drama that includes our own history as a species. But it is a very incomplete and limited story, both scientifically and metaphorically, based upon an inadequate view of organisms; and it invites us to act in a limited way as an evolved species in relation to our environment, which includes other cultures and species. These limitations have contributed to some of the difficulties we now face, such as the crises of environmental deterioration, pollution, decreasing standards of health and quality of life, and loss of communal values. But Darwinism short-changes us as regards our biological natures. We are every bit as co-operative as we are competitive; as altruistic as we are selfish; as creative and playful as we are destructive and repetitive. And we are biologically grounded in relationships which operate at all the different levels of our beings as the basis of our natures as agents of creative evolutionary emergence, a property we share with all other species. These are not romantic yearnings and utopian ideals. They arise from a rethinking of our biological natures that is emerging from the sciences of complexity and is leading towards a science of qualities which may help in our efforts to reach a more balanced relationship with the other members of our planetary society.

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