Preface

The aim of this book is to discuss the phenomenon of life, including its origin and evolution (and also including human cultural evolution) against the background of thermodynamics, statistical mechanics and information theory. The second law of thermodynamics states that the entropy (disorder) of the universe always increases. The seeming contradiction between the second law of thermodynamics and the high degree of order and complexity produced by living organisms will be a central theme of the book. This apparent contradiction has its resolution in the information content of the Gibbs free energy which is constantly entering the biosphere from outside sources, as will be discussed in detail in Chapter 4.

The book begins with a sketch of the history of evolutionary thought and research not only during Charles Darwin's lifetime, but also before and after him. Among the pioneers of evolution whose work will be discussed are Aristotle, Condorcet, Linnæus, Erasmus Darwin, Lamarck, and Lyell. They laid the foundations upon which Charles Darwin built his theory.

After Charles Darwin's death in 1882, the theory of evolution continued to develop and continued to be strengthened by newly discovered facts. Modern molecular biology and DNA technology have allowed us to construct evolutionary family trees in a far more precise way than Darwin and his contemporaries could do on the basis of morphology. Data from comparative sequencing of macromolecules have, on the whole, confirmed the 19th century picture of evolution; but they have also supplied much knowledge which was not available to the early pioneers of evolutionary theory.

Darwin visualized evolution as taking place through natural selection acting on small inheritable variations in the individuals of a species; but we now know that variations can sometimes be sudden and large - through mutations of the type studied by De Vries and Muller, or through the still more drastic mechanism of symbiosis and genetic fusion.

Darwin speculated on the origin of life, but he deliberately omitted discussion of this subject from his publications. However, in the last letter which he is known to have dictated and signed, he wrote: "... the principle of life will hereafter be shown to be a part or consequence of some general law." In our own time, researchers such as A.I. Oparin, Herald Urey, Stanley Miller, Melvin Calvin. Sydney Fox, Leslie Orgel, Carl Sagan, Manfred Eigen, Christian de Duve, Erwin Schrödinger, Claude Shannon, and Stuart Kauffman have begun to uncover this general law.

In the picture that has begun to emerge from the work of these researchers, the earth originally had an atmosphere from which molecular oxygen was almost entirely absent. Energy sources, such as undersea hydrothermal vents, ultraviolet light, volcanism, radioactive decay, lightning flashes, and meteoric impacts, converted the molecules of the earth's primitive ocean and atmosphere into amino acids, nucleotides, and other building blocks of living organisms. Energy-rich molecules, such as H_2S, FeS, H_2, phosphate esters, pyrophosphates, thioesters and HCN were also produced. Since no living organisms were present, and since molecular oxygen was absent from the early atmosphere, the energy-rich molecules were not degraded immediately, and they were present in moderate concentrations in the primitive ocean.

One then visualizes an era of "chemical Darwinism", in which autocatalytic systems competed for the supply of precursors and energy-rich molecules. These autocatalytic systems (i.e. systems of molecules which catalysed the synthesis of themselves) can be thought of as the precursors of life. They not only "ate" the energy-rich molecules present in the early ocean; they also reproduced; and they competed with each other in a completely Darwinian way, random variations in the direction of greater efficiency being selected and propagated.

An extremely interesting aspect of the picture just discussed is the special role of the energy-rich molecules. They play a special role because the process of molecular Darwinism at first sight seems to be violating the second law of thermodynamics - creating order out of disorder, when according to the second law, disorder ought to be continually increasing. If we reflect further along these lines, all forms of life seem at first sight to be creating order out of disorder, in violation of the second law.

Living organisms are able to do this because they are not closed systems. If we look at the "fine print" of the second law of thermodynamics, it says that the entropy (or disorder) of the universe always increases - and of course it does. Living organisms produce order within themselves and their immediate environments by creating disorder in the universe as a whole. The degradation of food into waste products is, in fact, the process through which life creates local order at the expense of global disorder. Life builds amazing displays of local order; but meanwhile, the disorder of the larger system increases. The larger system includes the sun, the earth, and the cold dust clouds of interstellar space.

In the hypothetical picture of the origin of life presented above, the "food" molecules are degraded by the autocatalysts in the process of order-creating molecular evolution. In Chapter 4 of the present book, we will focus on the entropy relationships in this process. The statistical mechanics of Maxwell, Boltzmann and Gibbs will be compared with information theory, as developed by Claude Shannon and others. It will be shown that Gibbs free energy carries a content of information and that the "thermodynamic information" obtained by the autocatalysts from the free-energy-rich molecules in the primitive ocean was the source of the order which developed during the process of chemical evolution.

Today, the earth's greatest source of thermodynamic information is the flood of free energy which reaches us in the form of photons from the sun. In Chapter 4, a quantitative relationship will be derived connecting the energy of an absorbed photon and its information content. Readers who wish to skip the mathematics in Chapter 4 may do so without losing the thread of the argument, provided that they are willing to accept on faith the main result of the derivations - the fact that Gibbs free energy contains the thermodynamic form of information.

It seems probable that thermodynamic information derived from free energy was the driving force behind the origin of life. It is today the driving force behind all forms of life - behind the local order which life is able to produce. This is the "general law" which Darwin guessed might someday be shown to underlie the principle of life. All of the information contained in the complex, beautiful, and statistically unlikely structures which are so characteristic of living organisms can be seen as having been distilled from the enormous flood of thermodynamic information which reaches the earth in the form of sunlight.

Where do humans fit into this picture? Like all other forms of life on earth, humans pass information from one generation to the next, coded into the base sequences of their DNA. However, humans have developed a second, highly effective mode of information transmission - language and culture.

Although language and culture are not unique to our species, the extent to which they are developed is unique on earth. Thus humans are distinguished from other species by having two modes of evolutionary change - genetic evolution, symbolized by the long information-containing DNA molecule, and cultural evolution, which might be symbolized by a book or a computer diskette.

If we compare these two modes of evolution, we can see that genetic evolution is very slow, while cultural evolution is extremely rapid - and accelerating. The human genome has changed very little during the last 40,000 years; but during this period, cultural evolution has altered our way of life beyond recognition. Therefore human nature, formed to fit the way of life of our hunter-gatherer ancestors, is not entirely appropriate for our present way of life. For example, human nature seems to contain an element of what might be called "tribalism", which does not fit well with the modern world's instantaneous communications and increasing interdependence.

Not only does the genetic evolution of humans lag behind their cultural evolution, but also cultural evolution itself has a rapidly-moving component and a slowly-moving component which lags behind, creating tensions. As we enter the 21st century, technology is developing with phenomenal speed, while social and political institutions change far more slowly. The disharmony thus created requires study and thought if human society is not to be shaken to pieces by the rapidity of scientific progress.

Interestingly, information technology and biotechnology, the two most rapidly developing fields, are becoming increasingly linked, each finding inspiration in the other. Biologists have studied the mechanism of self-assembly of supramolecular structures such as cell membranes, viruses, chloroplasts and mitochondria. Researchers in the field of nanoscience are now attempting to use this principle of supramolecular organization, observed in biology, to reach a new degree of miniaturization for the switches and memory devices of information technology. Simulated evolution, modelled after biological evolution, has been used to develop new and unorthodox computer hardware and software. Meanwhile, computers and automation are becoming more and more essential to biotechnology; and in fact many universities now have departments devoted to bioinformatics. Chapter 7 will trace the history of information technology, while Chapter 8 will discuss the ways in which it is merging with biotechnology.

The final chapter of the book looks at the future of the new field, bioinformation technology, attempting to predict what it will achieve during the new century, and discussing how these achievements will affect society.

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