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The evolution of biological information. How evolution creates complexity, from viruses to brains

I have occasionally mentioned biological information in my lectures and writing, usually citing the case of slime moulds (a very primitive form of life) which communicate through the emission of a chemical when they reach a certain stage in their development (Newell, 1977; Wilson, 2010). Adami, however, goes well beyond a simple illustration of this kind, and identifies information as crucial to the development of all biological organisms, from (as the sub-title tells us) viruses to brains.

This is not a popular science book: the author uses Shannon's information theory as the basis for his analysis of information processes in biological organisms and a certain level of mathematics is required for a full understanding. Exercises, mainly mathematical, are also presented at the end of each chapter, so the book is intended as a text book for advanced courses in biology.

The story begins in Chapter 1 with an account of the origins of Darwinism, or the theory of evolutionary change. The account sets out Darwinism in the context of the work of other "evolutionists" of the time and of scientists whose work provided Darwin with the background for the development of his theory. Chapter 2 moves on to explore the role of information theory, which allows the author to explore the information content of DNA, RNA, and protein sequences. The author notes that information theory might tend to "wash out" variation in genetic elements, but it does allow trends to be followed.

Chapter 3, *The evolution of information*, suggests that "*life did not start out with vanishing information: the problem in understanding the origin of life lies in part in understanding how the minimal amount of information necessary to sustain self-replication can come about*". The author goes on to propose that information (possibly in the form of ribonucleic acids) entered proteins at an early stage in the development of life, and evolved from that point on, referencing more and more complex genetic phenomena.

A variety of *Experiments in evolution* are described in Chapter 4, notably the Lenski experiment with *E. Coli* bacteria, which has so far been running for 36 years, and the author's own Avida digital life experiment. The author notes that these, and other, experiments have all, so far, supported Darwin's theory.

Whatever the origins of life on earth (and scientists are still not sure how it came about) it is evident, simply from looking at the world around us, that from what must have been extremely simply organisms, perhaps floating in the sea, or growing in some way, on rocks beside the sea, considerable complexity has evolved. Chapter 5 deals with the emergence of this complexity in information theoretical terms, and Chapter 6 deals with another evident characteristic of life: its robustness. The fact that species survive and evolve over time is evidence enough of robustness: mutations play a significant role, since it is through mutation that fitness to survive can develop.

The origin of life, in informational terms, is dealt with in Chapter 7, with the suggestion that RNA might have been the original information carrier. This is a well-established idea, generally known as the "DNA World Hypothesis" (RNA World, 2024). RNA is made up of nucleotides, like DNA, which form a sequence, which can encode information, and some RNA molecules have the ability to selfreplicate, which again suggests that information is being carried and transferred in this process. The key element of the hypothesis is that RNA emerged before DNA and proteins.

It has been suggested that Darwin's theory does not account for the phenomenon of cooperation; that is, cooperation to the extent of potentially suffering harm in order to protect someone else. Chapter 8 deals with this phenomenon and concludes that cooperation is favoured by evolution as long as the players in the situation can be relied upon to return the favour, which is conclusion also reached by game theorists.

In Chapter 9 we move on to *The making of intelligence*, not simply in humans but in a wide range of biological organisms from bacteria to man. The elements of intelligence are found in this wide range, from bacteria able to determine the state of a nutrition gradiant in the media they are developed, through scrub jays, which refrain from caching food if other jays are watching, as they know that, in such a case, their food would be stolen, just as they steal the caches of others, to human beings. The elements of intelligence are shown to be the ability to make predictions (just a few seconds ahead in the case of bacteria, to indeterminate periods of time in the case of humans); categorisation; memory; learning and inference; representation; and planning. Each of these is discussed in detail, with illustrations of how information theory can help us to understand these processes.

In the final chapter the author identifies (from a range of possibilities) three roles of information in biology. First, information distinguishes life from nonlife – life makes the storage of information possible: when a person dies, for example, the genetic group of which that person was a part continues to exist and includes the genetic information that constituted the dead individual. Secondly, the ability to communicate information is the basis of all collaboration, from one-to-one to societal. And, finally, information is used by living organisms to predict the future state of the environment, from that bacterium's ability to sense the future state of the nutrient gradient, to the human weather forecaster, or indeed, the average human's ability to sense that rain is possible and, therefore, an umbrella is advised.

This is a fascinating book, which presents a persuasive argument that much of what is puzzling in biology can be clarified by the use of information theory, giving information its major role in biological processes. It is probably of main value to advanced courses in biology, at the Master's level, and in preparation for the PhD, but any information scientist would find it rewarding.

References

Newell, P.C. (1977). How cells communicate: the system used by slime moulds. *Endeavour*, 1(2), 63-68.

RNA World. (2024). *Wikipedia.* https://en.wikipedia.org/wiki/RNA_world

Wilson, T.D. (2010). Information and information science: an address on the occasion of receiving the award of Doctor Honoris Causa, at the University of Murcia, September, 2010. *Information Research*, 15(4) paper 439. http://InformationR.net/ir/15-4/paper439.html