Degeneracy in Biological Systems

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1 Introduction

Darwin's theory predicts that during the process of evolution natural selection would force the genomes to increase in complexity. A feature of biological complexity is degeneracy - the ability of structurally different elements to perform the same function. Degeneracy is a ubiquitous biological property at all levels of organization. It increases both robustness of biological networks and their adaptibility to unforeseen environments and is hence favoured by natural selection.

The differnce between degeneracy and functional redundancy is subtle. In the latter case many elements can affect the output in a similar way but they dont have any independent function. This essay aims at bringing out the difference between degeneracy and redundancy by arguing that it is the former that contributes to robustness and adaptibility of organisms to changes in the environment.

2 Degeneracy at different levels of biological organization

Degeneracy had been observed in many biological systems ranging from genetic code to immune responses to neural networks. [1] A few examples are discussed below:

2.1 Genetic code

The genetic code that relates sequences of polypeptides and ployneucleotides is degenerate. We can make 64 possible triplet codons out of the 4 neucleotide bases. But actually there are fewer number of amino acid residues. As a result amino acid sequence of a particular protein can be generated by translating an enormous number of mRNA species. It has been observed that substitution of one amino acid residue by another at some sites of the polypeptide chain does not change the overall protein conformation or function.

2.2 Olfactory system

The discriminatory capacity of the mammalian olfactory system is such that thousands of volatile chemicals are perceived as having distinct odors. Malnic *et al.* [4] have shown that one odorant receptor recognizes multiple odorants and that one odorant is recognized by multiple receptors, but that different odorants are recognized by different combinations of ORs.

2.3 Immune System

The key idea on which all immune systems work is the ability to generate very large degenerate population of antigen-recognition sites. The degeneracy of the immunoglobins ensures protection against essentially any foreign infectious agent.

2.4 Nervous System

The degree of degeneracy in neural connectivity is enormous. Typically, neurons in the brain receive synaptic input from many thousands of other neurons. In humans, there are about one billion synapses in each cubic millimeter of brain grey matter. The pattern of connectivity created by so many synapses within such a tiny region could not be genetically prespecified. Neural connectivity is thus unique to each individual. Again no two neural cells within an animal are of identical shape. This degeneracy in connectivity is manifested in the gross anatomy of animal brains. For example, people who do not form the corpus callosum (the fiber tract connecting two cerebral hemispheres) have been reported to be quite asymptomatic to the disorder. The subtle abnormalities can be detected through detailed psychological testing.

3 Degeneracy and Redundancy

Redundancy as opposed to degeneracy is the case when the same function is performed by *identical* elements. For a system to be degenerate it has to be redundant. But complete redundancy would mean that the elements are incapable to contribute independently and hence do not respond to changes in the environment. Nonisomorphic but isofunctional structures on the otherhand can respond differently when the context is changed. This results in an extremely adaptible and robust system favoured by natural selection.

4 Degeneracy and Complexity

A complex system may be considered to be one in which there is an interplay between functional specialization and functional integration. The system should have smaller parts that are differentiated over a diversity of functions and at the same time should show functional integration when more and more elements are added to it. The relation between degeneracy and complexity can be intuitively understood from the fact that below a certain level of complexity, degeneracy would be low or nonexistent. The findings of Tononi *et al.* [2] suggest that high complexity values may reflect the statistical structure of a complex environment as well as responses to various selective pressures with multiple alternatives yielding adaptive outputs.

5 Degeneracy and Evolution

Degeneracy is a prerequisite of biological evolution because natural selection can only operate among a population of genetically dissimilar organisms. Natural selection has no way to uniquely map gene function to a particular phenotypic feature. Hence degeneracy is favoured by natural selection. The result is increased robustness as can be illustrated by the following exmaple. [3] Albumin is the most abundant protein in the plasma of mammals and plays an indispensible role in intercellular functions. Surprisingly, it is observed that this protein is completely absent in a population of randomly chosen healthy humans. Clearly, this is a consequence of functional degeneracy of albumin.

6 Conclusion

We observe that a system which has large number of nonisomorphic elements performing the same function, shows a high level of degeneracy. Unlike redundant elements, degenerate elements can produce new and different outputs under different constraints. A degenerate system is thus extremely adaptable in response to unpredictable changes in context and output requirements. It is therefore both necessary and inevitable outcome of natural selection.

References

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