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A Study of the Properties of the Standard Genetic Code

Summary

The standard genetic code (SGC) describes how the genetic information stored in a DNA molecule is transferred into the world of proteins. The properties of this code, especially its robustness against the effects of amino acid replacements resulting from codon mutations, have not yet been sufficiently studied and fully understood. Therefore, in this work, the problem was approached from the perspective of the optimization method. Special versions of evolutionary algorithms were prepared to find both the genetic codes minimizing the effects of point mutations and the codes maximizing them, in order to compare the features of the SGC with the properties of the codes representing the most extreme cases from the entire space of theoretical genetic codes. The methods applied in this work have led to more reliable results regarding the optimality of the standard genetic code than the methods used in previous studies which utilise its comparison with randomly chosen genetic codes, unrepresentative for all possible theoretical codes.

The results of the conducted analyses imply that the SGC has general tendencies of reducing the changes in polarity of replaced amino acids, although it is not optimal regarding this property. Furthermore, the SGC is characterized by varied robustness against the effects of nucleotide substitutions depending on which position in codon is substituted. It is almost optimal regarding the reduction of consequences of mutations in the third position in the codon, but it is worse at reducing errors resulting from mutations in the first and second codon positions. Despite the abilities of minimizing the consequences of substitutions, the very structure of the standard genetic code shows little resemblance to the structures of optimized theoretical genetic codes.

The SGC tends to limit changes not only in the polarity of substituted amino acids, but also in their tendencies to form the appropriate secondary structures and other physicochemical properties. However, the SGC is not fully optimal in this respect.

In this work, the properties of the alternative genetic codes were also examined, in relation to the standard genetic code and theoretical genetic codes with similar structures. The analyses

showed that the vast majority of alternative genetic codes limits the consequences of point mutations and errors during translation better than the SGC. This code is not even in the local optimum of genetic codes with similar structure, because a change in the assignment of even one codon can improve the robustness of this code against amino acid replacements in terms of their polarity by 15%, and changes in the assignments of three codons can improve this robustness by nearly 50%. Furthermore, the alternative genetic codes reduce the consequences of mutations better than most theoretical genetic codes differing from the standard genetic code by assignments of one, two, or three codons.

The results of this work suggest that minimizing the consequences of mutations and errors during translation played a certain role in the evolution of the standard genetic code, but it was not the only factor. In turn, many changes leading to the emergence of alternative genetic codes could have been accepted because of their properties in reducing the effects of amino acid replacements and the generation of STOP translation codons.