Definition of biological robustness and biological fragility

Biological robustness is the property that allows a system or an organism to maintain its functions against external or internal perturbations. Such a definition of biological robustness doesn't mean that the system or organism stays unchanged when external or internal perturbations occur, and its structure, components, and operation mode are unaffected. On the contrary, such robustness refers to the property that when mutations and stimuli appear, the system changes its mode of operation, or its structure and components flexibly, and at the cost of change to maintain its function [1].

Biological fragility is more like a trade-off of biological robustness. According to Yung-Keun Kwon et al.[2], biological fragility is defined as the probability with which the robustness can be lost by unexpected mutations. It is a by-product as well as a cost of improved biological robustness. More specifically, once a system is robust against certain perturbations, it will lead to extreme vulnerability to unusual or unexpected perturbations. And such a phenomenon is biological fragility.

Examples of biological robustness and biological fragility

For biological robustness, the most easily thought-of example is the degeneracy of codons. Except for methionine and tryptophan, every amino acid has at least two codons. In this way, to a certain extent, the amino acid sequence will not cause amino acid errors due to the accidental replacement of a base. This is the robustness of organisms to internal disturbance. Even if the base in the codon is changed, it can still encode the original amino acid. The code's degeneracy also makes the DNA molecule's base composition change a lot. Apart from this, many investigations on robustness are held. For example, Escherichia coli is capable of chemotaxis over a wide range of chemo-attractant concentrations because integral intracellular feedback can ensure perfect adaptation and it is independent of ligand concentration[3], such result is also a reflection of biological robustness.

Most intuitively, biological fragility is the loss of certain functions. Taking respiratory alkalosis as an example, when the respiratory system of the human body is subject to external abnormal interference, such as hypoxia, hyperventilation, etc., it will lead to the primary reduction of plasma H_2CO_3 concentration or $PaCO_2$, which will lead to the increase of pH value, causing adverse reactions to the body. The same is true for ecosystems. When external species invade or internal species change suddenly, the ecosystem will also collapse. And this is also the embodiment of biological fragility.

The necessity of biological robustness

As mentioned above, robustness is the key element of normal function when encountering perturbations. The survival of a species or system will inevitably require the use of unreliable components in unpredictable environments[1]. For this reason, biological robustness can use these components in different ways and ensure the maintenance of normal functions to meet survival needs, thus biological robustness is a necessary part of survival.

On the other perspective, robustness guarantees a complex system is evolvable as the robust traits consistent with the survival demands of the environments are more likely to be kept and make it viable for the system to evolve. Such evolution is a treatment to resist both environmental and genetic perturbations for survival.

Since biological robustness is vital for guaranteeing the current survival, using different components to prevent interference, and ensure that the system can evolve and retain more suitable characteristics for survival as well, is without doubt an integral part of survival

The consequence of fragility and how to avoid it

As a result of biological fragility, disease is the most common manifestation of a single organism. For the system, dysfunction is the result of biological fragility.

The avoidance of biological fragility is a huge and complex process because biological systems are complex and dynamic. According to previous research, the number of feedback loops is an indicator of fragility[2,4]. Therefore, with a deep understanding of the loop, protecting the extant loops and supervising unpredictable mutations in a network may help to improve the robustness of the system and avoid fragility. Besides, system controls, modularity, alternative mechanisms and decoupling serve are basic mechanisms to provide robustness to the system[1]. Full utilization of these mechanisms needs coherent organization to enhance system's robustness, as well preserving the core function, but system control is the prime mechanism for coping with environmental perturbations that require proper dynamics.

Reference

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