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Answer to Question 1

Topic: Biological Robustness and Fragility

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Biological Robustness and Fragility

目录

1. **Definition**

This is an essay about ‘Biological Robustness and Fragility’. First of all, we need to know what is 'Robustness' and what is 'Fragility'?

Robustness is a property that allows a system to maintain its functions against internal and external perturbations (Kitano, 2004) . On the contrary, fragility, as a noun form of ‘fragile’, represent the property of being easily broken or destroyed.

Transferring these two concepts into the field of biology, biological robustness is a system property to keep a stability of live-body structure and function as uncertainty factor from external and internal variety disturbs it, while biological fragility represents that a biological system is prone to disintegration due to disturbances by the perturbations that might affect the system’s functional body.

2. **Examples**

I will introduce two examples about ‘Biological Robustness and Fragility’ respectively here.

2.1 **Example of robustness**

Let we consider the developmental robustness. During human evolution and development, we suffer many

Perturbations. Perturbations can be internal for an organism or external (Masel, 2009). Internal perturbations include uncontrollable stochastic or microenvironmental variation, for instance, genetic variation upon heritable mutation accumulation and recombination. External perturbations are commonly environmental changes such as temperature, nutrient concentration, humidity and photoperiod that are likely to affect growth and development (Mestek Boukhibar, 2016). Although we experience these internal and external disturbances all the time, human fate pattern is highly robust to stochastic and environmental variation. We still grow and develop steadily, and our developmental system maintains its own stability, at least for hundreds of years.

2.2 **Example of fragility**

Highly optimized tolerance (HOT) theory demonstrates, taking the example of a forest fire, that a system that is optimized for a specific perturbation inevitably entails extreme fragility for unexpected perturbations (Carlson J.M., 1999) If one decides to plant all trees around a city in a circular manner to be able to cope with fire from any direction, such design may actually allow a fire to spread and encircle the city, causing major damage to the city as well (B). However, if one cuts all the trees in the field, the city will be very fragile against the rainy season as flooding will be more likely due to the resulting loss of water-absorbing capacity of the trees (KitanoH., 2007).

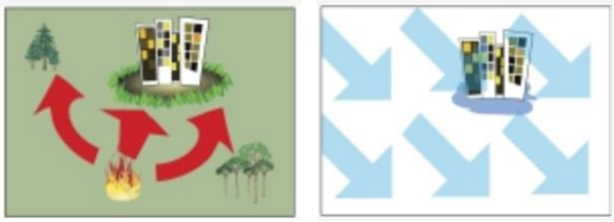

Figure 2.1 Fragility in forest fire countermeasures

3. **Biological robustness is integral part of survival.**

As for the evaluation, robustness facilitates the evolvability of complex dynamic systems. Evolution, given enough time, might select a robust trait that is tolerant against environmental perturbations. This interlinks the properties of robustness and evolvability. Robustness is ubiquitous in biological systems that have evolved (Kitano, 2004). Consider the most important evolutionary relevant phenomenon: gene duplications. In fact, a large fraction of genes in a wide range of genomes is easily recognized as the product of gene duplication, especially in the eukaryotic branch of the tree of life (Zhang, 2003). The networks that are better at maintaining the original phenotype after duplication are usually also better at buffering the effect of single interaction mutations and that duplication tends to enhance further this ability. Moreover, those phenotypes that had easier access through mutation before duplication had higher chances of remaining accessible through new mutations after duplication. Nonetheless, since organisms are regularly subject to environmental fluctuations, developmental noise and other non-genetic disturbances, direct selection for robustness against such perturbations is feasible (Posadas-García, 2022). It can be seen that in the process of evolution, gene duplication tends to retain the original shape and weaken the impact of changes brought about by single mutations on the organism. Here is the embodiment of the robustness of growth and development. This phenomenon enables organisms to better ensure the stability of organism living in an unpredictable external environment. This is more conducive to survival. In addition, in large populations, the high frequency of mutations in the same direction may reflect the direction of species evolution. Mutations that occur during gene duplication are also more likely to progress to the shape that appeared before. The robustness of this gene variation also strengthens the evolutionary ability of the species, which is conducive to the long-term reproduction and survival of the species.

4. **Consequences of fragility**

4.1 **What are the consequences of fragility**

When a biological system exhibits fragility, it cannot resist perturbations to itself well, and may even cause irreversible results. For example, the ecological environment of the tropical rainforest is very fragile, the soil is poor, and it is extremely difficult to recover once it is destroyed; because the biological cycle in the tropical rainforest is extremely vigorous, the recycling of organic matter and nutrients is also very strong. However, the nutrients in the rainforest are almost all concentrated in the plants and very little in the soil. Once the rainforest is destroyed and the nutrients on the surface are washed away by water, the fertility of the entire land will drop sharply, and it will be difficult for the plants on the surface to recover. This is the key to its fragility.

4.2 **How one could avoid it**

To avoid the problem of biological fragility, we must first understand the reasons for this situation. For those systems that cannot effectively improve themselves temporarily, the most effective way to avoid damage caused by vulnerability is to prevent early through early risk warning. Using the same example of tropical rainforests, researchers report July 23 in the journal One Earth that they have developed a new method to track the vulnerability of these forests globally using satellite data. The new approach, called the Tropical Forest Vulnerability Index (TFVI), is hoped that it will serve as an early warning of the most threatened areas so that action can be taken to protect these forests before it is too late.

Of course, if fragilities can be avoided by improving the properties or activities of the system itself, it should be very efficient, once and for all. Lack of sleep is known to impair learning, memory and immune function, and delay wound healing. This results in a certain degree of increased biological vulnerability. In a new study published in Science Advances, a team of researchers led by Northwestern University studied the brain activity and behavior of fruit flies and found that deep sleep can clear the brain of waste products, including waste products that may lead to Toxic proteins in neurodegenerative diseases. To test whether preventing the flies from sleeping would affect their waste removal, the researchers injected the flies with a non-metabolic dye. They found that flies had a reduced ability to clear non-metabolized dyes from their bodies and were more vulnerable to trauma. This suggests that sleep deprivation during sleep deprivation is accompanied by a loss of waste-clearing functions. It can be seen that sleep to a certain extent avoids the increased fragility of the organism.

Reference

[1]Carlson J.M., D. J. (1999). Highly optimized tolerance: a mechanism for power laws in designed systems. *Physical review. E*, Statistical physics, plasmas, fluids, and related interdisciplinary topics, 60(2 Pt A), 1412–1427.

[2]H, K. (2007). Towards a theory of biological robustness. *Molecular systems biology*, 3, 137.

[3]Kitano, H. (2004). Biological robustness. *Nature Reviews Genetics*, 5(11), 826-837.

[4]KitanoH. (2007). Towards a theory of biological robustness. *Molecular systems biology*, 3, 137.

[5]Masel& Siegal, M. L.J.,. (2009). Robustness: mechanisms and consequences. Trends in genetics : TIG, 25(9), 395 – 403.

[6]Mestek Boukhibar, L. &. (2016). The developmental genetics of biological robustness. *Annals of botany*, 117(5), 699–707.

[7]Posadas-GarcíaEspinosa-Soto, CY.S.,. (2022). Early effects of gene duplication on the robustness and phenotypic variability of gene regulatory networks. BMC Bioinformatics, 23, 509.

[8]ZhangJ. (2003). Evolution by gene duplication: an update. Trends in ecology & evolution, 18(6), 292-298.