Biological Robustness and Fragility

Biological robustness is a key property that allows biological systems to function effectively in the face of external and internal perturbations. There are three types of robustness at different levels: mutational robustness at the module level, robustness to stochasticity at the individual level, and environmental robustness at the ecosystem level [1]. This can be ubiquitously observed in various biological examples, such as chemotaxis in bacteria, gene mutation, biological development, and so on [3]. Taking bacteria as an example, the fate decision of its life cycle is robust against small perturbations at its promoter region [4].

Fragility is the opposite of robustness. It refers to losing the robustness of biological networks caused by unexpected or unusual mutations [2]. For instance, the immune system is fragile when comes to unexpected failures such as dysfunction of MyD88, which is a nonredundant core element [5]. Fragility can lead to serious consequences, such as the loss of function or even failure of the system leading to illness or death.

Biological robustness is essential for survival. It involves positive and negative feedback loops, which are ubiquitous in our daily life. From an individual perspective, our cells are constantly dividing and transcribing DNA, and sometimes errors can occur in the transcription process. In this case, biological robustness helps repair the affected genes. For example, the negative feedback loop between MDM2 and p53 helps maintain optimal levels of p53 and produces specific dynamics of p53 expression levels in response to DNA damage [6]. Without robustness, the health system would become unstable, and our body's general functions would be damaged at the genetic level.

To avoid biological fragility and promote robustness, there are 2 recommendations:

First of all, providing good protection for those nonredundant and non-renewable components and increase their durability. A robust biological network is easily fragile against unexpected mutations at the nodes not previously exposed to perturbations [2], which are often important and frail. These nodes lack experience of perturbations and once they get attacked, their topological structures are much more fragile than others, so maybe providing good protection for these nodes and enhancing their robustness helps.

The second recommendation is to keep the randomness and diversity in the bio-system, which can make it more resilient to perturbations. Biodiversity helps to maintain the balance of ecosystems, which can be disrupted by the loss of species. For example, the loss of a predator species can lead to an overabundance of its prey, which can have cascading effects on the rest of the ecosystem. Due to a lack of natural predators, Australia was overrun by European rabbits in 1859, which caused great environmental damage. Thereafter, experts introduced some wolves to kill these rabbits and finally solve the problem [7]. In this case, we can see the importance of keeping biodiversity for avoiding fragility in the system.

Overall, robustness is essential for the survival and functioning of biological systems, and it is important to understand and promote it in order to maintain the health and well-being of individuals and the planet.

Reference

[1] Robustness (evolution). (2022, October 16). In Wikipedia. https://en.wikipedia.org/wiki/Robustness_(evolution)

[2] Yung-Keun Kwon, Kwang-Hyun Cho, Quantitative analysis of robustness and fragility in biological networks based on feedback dynamics, *Bioinformatics*, Volume 24, Issue 7, 1 April 2008, Pages 987–994, https://doi.org/10.1093/bioinformatics/btn060

[3] Bing Zhu, Jiali Bao & Lei Ying (2007). 生物鲁棒性的研究进展. 生物物理学报 (05), 357-363.

[4] Little, J. W. et al. (1999) Robustness of a gene regulatory circuit. EMBO J., 18, 4299-4307.

[5] Kitano, H. and Oda, K. (2006) Robustness trade-offs and host-microbial symbiosis in the immune system. Mol. Syst. Biol., 2, E1–E10.

[6] Lev, Bar-Or et al. (2000) Generation of oscillations by the p53-mdm2 feedback loop: a theoretical and experimental study. Proc. Natl Acad. Sci., 97, 11250-11255.

[7] "How European Rabbits Took Over Australia." National Geographic Society, https://education.nationalgeographic.org/resource/how-european-rabbits-took-over-australia. Accessed 20 Dec. 2022.