Biological Robustness and Fragility

CHENGLE OUYANG

1 Definition

Biological robustness refers to a property of biological system to maintain its structure and function robustness when interfered by uncertain factors such as external disturbance or internal parameter perturbation [1].

Fragility refers to the ability of biodiversity to withstand changes in external conditions. A higher Fragility means that biodiversity is easily affected by external conditions to change, and is often vulnerable to unexpected mutations [2]. The robustness of biological networks is vulnerable to unexpected mutations.

2 Examples

At present, it has been found that biological robustness is universal in the whole biological system, organ, cell, molecular and other levels, such as bacterial chemotaxis, cell cycle, cell signal communication, gene mutation, biological development, gene network and so on. E. coli can chemotaxis across a wide range of chemoattractant concentrations. For example, the concentration of network proteins can be greatly changed, but E. coli can still maintain accurate adaptation [3]. This indicates the robustness of chemotaxis of E. coli.

The robustness and fragility of biological networks are interrelated. Energy control systems ensure robustness to common disturbances such as unstable food supplies or infections, but the system can expose Fragility to overnourishment or glucose shortages. The immune system provides robustness against pathogen threats, but it is vulnerable to unexpected malfunctions, such as the dysfunction of MyD88, a non-redundant core element. Cancer cells are robust to a variety of chemical agents, but can be very vulnerable to certain disturbances.

3 Necessity of biological robustness

An organism is always in a changing environment, and it also needs a relatively stable internal environment to enable it to survive in all kinds of environments. Therefore, the existence of biological robustness enables organisms to better adapt to the environment and to maintain their functions from external and internal disturbances. Biological robustness is also reflected in the slow attenuation of functional characteristics of biological systems under the condition of damage (non-catastrophic failure), so as to enhance survivability and prolong survival time [5]. Understanding biological robustness is important for the occurrence, development and treatment of cancer, AIDS, diabetes and other diseases.

4 Consequences of fragility and How to avoid

Glucose deficiency or excess can expose Fragility in the volume control system and cause metabolic syndrome. Metabolic syndrome exhibits its own robustness, retaining persistent hyperglycemia and hyperinsulinemia. However, the presence of the syndrome is eventually confused by cardiovascular disease [4]. Node mutation involving a relatively large number of feedback loops may expose the Fragility of robust networks [2]. For example, deletion of p53 gene or functional protein can predispose organisms to cancer at a young age [6].

Many complex networks exhibit fragile behavior with relatively small changes in edge weights and interconnect structures. Such is the case with ecosystems, where fragility affects the chances of species co-existing in stable equilibrium [7]. For example, in neural networks, fragility means that small changes in the weight of certain synapses can suddenly induce erratic behavior and lead to seizures [8]. The fragility of complex networks is a negative feature that, neither natural evolution nor careful human design can remedy. Existing theories are insufficient to explain this phenomenon [9].Therefore, improving the robustness of complex networks and reducing perturbations, mutations, accidents can avoid exposing the Fragility of biological systems as far as possible.

Biomolecular regulatory networks are robust but fragile in terms of feedback loops [2]. The number of feedback loops is an indicator of fragility, and many fatal or basic nodes involve relatively more feedback loops. Thus, less feedback loops can reduce fragility.

Reference

[1] Bing, Z., Jiali, B. and Lei, Y., 2010. Progress of biological robustness.

[2] Kwon, Y.K. and Cho, K.H., 2008. Quantitative analysis of robustness and fragility in biological networks based on feedback dynamics. *Bioinformatics*, *24*(7), pp.987-994.

[3] Alon, U., Surette, M.G., Barkai, N. and Leibler, S., 1999. Robustness in bacterial chemotaxis. *Nature*, *397*(6715), pp.168-171.

[4] Kitano, H., Oda, K., Kimura, T., Matsuoka, Y., Csete, M., Doyle, J. and Muramatsu, M., 2004. Metabolic syndrome and robustness tradeoffs. *Diabetes*, *53*(suppl_3), pp.S6-S15.

[5] Yang S K. Steroid microbial transformation: Robust biotransformation of glucocorticoid hydrocortisone and its application [J]. Chinese Journal of Applied & Environmental Biology, 2022(001):028.

[6] Malkin, D., Li, F.P., Strong, L.C., Fraumeni Jr, J.F., Nelson, C.E., Kim, D.H., Kassel, J., Gryka, M.A., Bischoff, F.Z., Tainsky, M.A. and Friend, S.H., 1990. Germ line p53 mutations in a familial syndrome of breast cancer, sarcomas, and other neoplasms. *Science*, *250*(4985), pp.1233-1238.

[7] Allesina, S. and Tang, S., 2015. The stability–complexity relationship at age 40: a random matrix perspective. *Population Ecology*, *57*(1), pp.63-75.

[8] Sritharan, D. and Sarma, S.V., 2014. Fragility in dynamic networks: application to neural networks in the epileptic cortex. *Neural computation*, *26*(10), pp.2294-2327.

[9] Pasqualetti, F., Zhao, S., Favaretto, C. and Zampieri, S., 2020. Fragility limits performance in complex networks. *Scientific reports*, *10*(1), pp.1-9.