Biological Robustness and Fragility

Yaning Zhang

Biological robustness is an important property that guarantees the system maintains its functions against external or internal disturbances. It is a systematic attribute, and not specialized to the individual. Robustness does not mean that the system has no changes when it encounters mutations, but it may make some behaviors to ensure normal function (Kitano, 2004). Biological fragility is that the system is likely to be attacked at unexpected mutations. A system is mixed by both robustness and fragility, and diseases are attributed to the exposed fragility. According to Kitano, biological robustness is aligned with evolutionary principles, and the complex system requires robustness to resist environmental and genetic perturbations, but there must be trade-off between biological robustness and fragility. If robustness is enhanced, there must be extreme fragility in other areas to balance (Lenski et al., 2006).

Biological robustness is maintained by four mechanisms: system control, alternative mechanisms, modularity and decoupling. As for system control, positive feedback and negative feedback are two major ways. Alternative mechanisms are that several methods can perform similar functions, so that if one of the methods fails, the system can replace it to maintain the normal operation of the system. Kitano gives an example about different ways to produce ATP, oxidative phosphorylation is one way to produce mass ATP, but when it is lack of oxygen, anaerobic glycolysis is another way to make ATP, even though the amount is not as huge as the first one. Modularity is that the system limits the influence on localized areas instead of the whole system by dividing the system into different modules to reduce damage, tissues and organs are evidence for modules in a system. The decoupling separates low-level variations and high-level features, so that it can deal with mutations but maintain the functionality of a system (Kitano, 2004).

An example of biological robustness is the biochemical network for bacterial chemotaxis. Bacteria such as Escherichia coli can know the chemical gradient in the solution, and its movement direction is associated with tumbling frequency. With the property that the steady-state tumbling frequency does not frequently change with the value of ligand concentration, bacteria can remain sensitive to chemical gradients throughout a broad range of attractant or repellent concentrations (Barkai & Leibler, 1997). An example of biological fragility is that the immune system may lose functions against unexpected mutations such as MyD88, a non-redundant core element (Kwon & Cho, 2008).

The importance of robustness is that it allows organisms to survive even when homeostasis has been disrupted. Robustness keeps balance on what should change and what cannot change, then organisms can retain the functions adapted to the environment or make appropriate changes under the influence of the environment, and survive over the years. Such changes show in physiological and evolutionary responses to changes in an individual's life, which the previous encoded information about environment or how to respond for the future is updated continually (Lenski et al., 2006). Robustness, unlike homeostasis, does not mean maintaining the state of the system, but rather means maintaining system functionality even as it transitions through a new steady state, or is in an unstable state. This state may be more helpful for the system to cope with disturbances. Dehydrated organisms such as tardigrades, which almost completely suspend metabolism under extreme dehydration, enter a dormant state to survive for many years, and became active again after rehydration (Kitano, 2007). In the face of sudden changes, robustness can ensure that the system performs its functions normally through self-regulation, which is very important for the survival of organisms.

The result of fragility is that the system is damaged or influenced. The result of the fragility in a forest system may be a fire that burns it; for human body, the consequence may be the invasion of mutated viruses and lack of corresponding antibodies. The method to avoid fragility is to enhance the understanding of it. Fragility and robustness balanced at the same time, so when people found the robustness of a system is very strong, the fragility will not at a low level relatively. Therefore, if people can understand the reason why the robustness of a system is strong, they should equivalently pay more attention on the aspects of fragility. Just like the human body, although there is no way to predict the invaded viruses in advance, regular inspection and prevention can help people understand the situation more comprehensively.

References

Barkai, N., & Leibler, S. (1997). Robustness in simple biochemical networks. *Nature*, *387*(6636), 913-917.

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

Kitano, H. (2007). Towards a theory of biological robustness. *Molecular systems biology*, *3*(1), 137.

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

Lenski, R. E., Barrick, J. E., & Ofria, C. (2006). Balancing robustness and evolvability. *PLoS biology*, *4*(12), e428.