Biological Robustness and Fragility

name: Zijie Cheng

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Organisms encounter various external perturbations every day. During the evolution of organisms, individuals that can better adapt to external perturbations will be selected, so the robustness of the biological system is also increasing. Enhanced robustness against certain perturbations has to be balanced by extreme fragility elsewhere. Robustness means the ability to maintain function in the face of perturbations and uncertainty, and fragility means after rare perturbations the steady state is broken and lost its robustness.

Here is an example for biological robustness and fragility: when human body faces external perturbations, such as sudden food supplement shortages, infections, the human body can adapt to such changes. These perturbations are not cause any disease or dysfunction for it. However, when a person has long-term disordered lifestyle and unhealthy diet, he may suddenly experience heart attack which means his heart cannot work properly as before. At this time, the human body can no longer adjust itself to adapt to these perturbations.

The robustness of the system that can adapt to perturbations can be divided into two types. One is non-gene mutation changes. When a perturbation occurs, the organism can gradually deviate from its original steady state. It may return to original steady state or transits to next steady state, stability is once lost, and the system regains its stability in the new steady state but retain its normal function. In extreme dehydration, for example, the metabolism of invertebrates is almost completely suspended, or even stopped, and they enter a dormant state, surviving for many years, a dormant state achieved by the mass production of algal sugars, and then becoming active again when rehydrated [1]. This is, on the contrary, a sign of biological robustness and is extremely important for the survival of the organism. The other is the change of gene mutation. The phenotype of each individual in a population is very similar because the robustness of the biological system selects more cryptic genetic variation, which realizes the accumulation of cryptic genetic variation and reduces the number of dominant genetic mutations. The accumulation of cryptic genetic variation improves the population's ability to adapt to external perturbations, while the reduction of dominant gene mutations improves the stability of biological systems. For example, people living near the North Pole are implicitly more resistant to cold, which is come from cryptic gene mutations, but they have similar phenotypes with people living in other regions.

Biological vulnerability results in the loss of its original function or expression and the inability to self-adjust to a new homeostasis. For example, diseases such as heart disease, diabetes and HIV cannot be self-regulated by individuals to return to their original steady state and require external intervention to treat the disease to return to its original homeostasis. Another example is forest, fires do not normally occur, but can be caused by accidents, such as dry weather leading to spontaneous combustion, or by man-made causes. This is the fragility of forests. We need to balance system robustness and fragility before fragilities are exposed. A network acquires robustness as it involves a smaller number of feedback loops for the nodes subject to perturbations while involving a larger number of feedback loops for the nodes under no perturbation. However, the robustness of a network becomes fragile when unexpected mutations occur at the nodes subject to no perturbation [2]. These feedback loops make biological network derives from its original steady state but when the number of feedback loops is too large to accept, it will result in sever accidents. So, if we design biological network with less feedback loop at the nodes subject to no perturbation, it will help us prevent unexpected result and reduce fragility. However, it will face trade off with biological robustness. After the vulnerability is exposed, we need systematic countermeasures to control robustness of an epidemic state. Countermeasures include systematic intervention to control a system's dynamics, attack fragility or introduce decoys to re-establish control.

**References:**

[1]: Kitano, Hiroaki, (2007) Towards a theory of biological robustness. Molecular Systems Biology, 3. 137. doi: 10.1038/msb4100179

[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