Biological Robustness and Fragility

Robustness is the capacity of a system to maintain its functionality even in the face of changes in the internal structure or external environment. While fragility means the sensitivity of a system to external disturbances and its ability to recover from them.

In biology, robustness refers to the ability of a biological system to maintain its structural and functional stability when disturbed by uncertainties such as external perturbations or internal parameter uptake [1]. Biological robustness is most clearly reflected in the adaptation of organisms to their environment and is a pervasive feature of biological systems. Organisms are subject to a large number of genetic and environmental changes and have evolved a variety of mechanisms to perform properly in the face of these challenges [2]. Phenotypes arise at all levels in the architecture of biological organization from gene products to biochemical signaling pathways, cells, tissues, organs and the whole body [1].

Generally speaking, robustness and fragility go hand in hand. What is robust in one aspect may be fragile in another aspect at the same time [3]. Biological organisms are highly robust when facing with environmental and component uncertainty, yet in the face of small genetic perturbations or the presence of microscopically visible pathogens, the organisms might be in danger [3]. Another typical example of this is the Internet. Processor chips are equally robust when there is a large change in the analogue performance of their circuit components, but can break down completely when a component is removed or the circuit is rearranged. Processors, memory and other chips can be used in highly fault-tolerant computers and networks to build platforms for complex software systems. These software systems are capable of performing a wide range of functions but could collapse when they encounter a single line of the error code.

Robustness is a key characteristic of biological networks, capable of maintaining their function against external and internal perturbations. This property is ubiquitous in a variety of biological examples. For example, the fate decision of the phage life cycle is robust to small perturbations of its promoter region [4]. E. coli is capable of chemotaxis at various chemical elicitor concentrations. Drosophila establishes segment polarity against perturbations in its initial values and molecular interaction rate constants. On the other hand, it is often said that biological networks are often fragile against unexpected mutations. For instance, our body’s energy control system ensures robustness to common perturbations such as unstable food supplies or infections, however the system is fragile to abnormal mutations such as high energy content foods or low energy utilization lifestyles [5]. The immune system provides robustness against pathogen threats but it is fragile to unexpected failures. The Drosophila segment polarity gene network shows robustness to perturbations in its initial conditions but shows fragility to large temporal variability.

Robustness plays a vital role in survival. Sometimes robustness could be seen as insensitivity to external and internal perturbations, while evolution requires entities to change their structure or function to adapt to changing circumstances [2]. One of the most important examples is the immune system. Billions of autonomous cells handle invading pathogens robustly and smoothly, regardless of the constant mutations of the pathogens which allow them to evade the immune attack [1]. Robustness is essential to survival due to that with robustness they could perform their functions in uncertain and changing environments.

If something is fragile, it is vulnerable to a particular injury, being destroyed, broken or damaged. Then special care needs to be taken to avoid the damage. It seems that healthy people basically take their health for granted. Good health is the invisible ground on which life depends [2]. Most of the time, we unreflectively expect our limbs to move and our senses to perceive without pain or other forms of malfunction. However, at least to some extent, this good health is fragile and an unexpected heart attack, spreading cancer, a mysterious bruise or severe pain could suddenly destroy the sense of well-being. Medicine seeks to overcome one of the most fundamental fragilities of the human condition. No matter how robust our current health is, we will inevitably suffer from future illnesses and these current illnesses remind us of the various fragilities inherent in the human condition. In cases of current poor health, patients and doctors are more likely to manage this fragility through diagnoses which could explain suffering and provide certainty about prognosis and treatment. Healthy people might take precautions including but not limited to various tests and screenings to protect their health from fragility [5]. Screening for many diseases is accepted as a routine part of health care that asymptomatic disease could be identified earlier.

References:

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