Question 1 Essay on understanding Biological Robustness

The term robustness is also used in data science field. With the definition of the degree, that model performance changes when using new data versus training data. It is a criterion to measure whether the model is flexible enough to handle new data. Based on my previous knowledge and understanding in data science and biology, I think biological robustness can be interpreted as a kind of ability that biological system can withstand adverse conditions. In a more specific way, it is a universal property to the biological system that adopts perturbation in internal or external factors by allowing certain changes in the system itself to maintain its own function. (Kitano, 2004) Like the machine learning model taking new data input to produce a certain result, the biological system takes a new environment and still makes the whole system work as normal and avoid collapsing. For example, in the level of gene transcription, The human body produces numerous new cells every day, which involves a lot of DNA transcription and inevitably some small errors. In most cases, these errors do not have a significant impact on human function. This is the robustness of the human body systems.

One sword has two sides, the robustness makes the whole system strong while bringing the fragility as the drawback to perform an inherent balance. To achieve high biological robustness, the system must add too many restrictions to ensure each module of it works exactly as it should be. They are like precision machines, with one gear tightly interlocked with the other. Once one of them receives an external disturbance and collapses, the operation of the whole machine will also be seriously affected. An example of this is Diabetes mellitus, which can be viewed as an exposed fragility of the system that has developed robustness against near-starvation, a high energy-demand lifestyle, and a high risk of infection, but is uniquely upset by over-nutrition and a low energy-demand lifestyle. (Kitano, 2004)

The reasons of biological robustness is essential to survival can be explained in two aspects, genetic mutation and evolution. Organisms need to evolve to survive by adapting themselves to their environment. Evolution is defined as the change in the gene pool of a population. It is important to produce genetic variation without allowing the variation to affect the survival of the entire population. It requires the ability to generate a heritable and selectable phenotypic variation to provide material for biological evolution. Herein lies the fact that the process of biological evolution goes hand in hand with biological robustness. Also, the external environment is keeping changing. This means that complex systems have evolvable architectural requirements, which essentially require systems that are robust to environmental and genetic disturbances. First, mechanisms that protect components and interactions from mutations must be able to generate genetic variation. Second, there must be modules that can robustly maintain their functions from external perturbations and mutations. (Kitano, 2004) For example, the coronavirus, which is rampant today, has produced many variants. Its ability to rapidly produce genetic mutations that do not affect the survival of its populations is so robust that the virus is still prevalent today.

Since fragility is the trade-off brought by biological robustness, the consequence of fragility directly impact on the whole biological system which shows strong robustness. It might lead to system collapse. The robustness of the organism is increased by successive additions to the regulatory system. However, the introduction of various control feedback loops can lead to instability when unexpected perturbations are encountered, which can lead to catastrophic failures. Systems that have evolved to be robust to general perturbations are extremely vulnerable to certain types of rare perturbations. A possible way to solve fragility is to achieve a dynamic balance between robustness and fragility. The question remains how to find the fragility. It is important to investigate what the system is optimized for and to identify the sources of robustness. The fragility points of the system must be associated with mechanisms to improve robustness. For example, in Kitano's study, Tumor robustness is maintained by various factors such as chromosome instability, intra-cellular feedback loops, and host-tumor interactions. To combat this, researchers are exploring various strategies, such as using multiple drugs to control the cell cycle, possibly through RNAi, targeting unstable chromosomes, delivering engineered genes to restore host-tumor interactions, or introducing artificial genetic circuits to conditionally express tumor-suppressor genes. The goal is to identify the fragility of the tumor and use this information to devise effective treatments.

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