Biological Robustness refers to a property of a system to maintain its normal functionality despite external or internal perturbations [1]. A simple example is human body temperature – if taken to a climatic temperature of 15C, or 50C we will be able to maintain an ambient body temperature of 37C. In this case, the perturbation is the changing climatic conditions and the robust functionality is the body's temperature regulation mechanism.

Another example of biological robustness may be seen in cancer cells [2]. The “functions” of tumour cells that are being preserved i.e are robust, are multiplication and survival, and medical therapies such as chemotherapy may be seen as perturbation to the “system”. The system maintains resistance to therapies by various mechanisms such as genetic diversity, and feedback loops to continue its function.

A system which is not resistant against perturbation or disturbance is said to be fragile. Consequence of fragility is that it makes a system more vulnerable to mutation. Robustness and fragility are often seen simultaneously, both affecting each other. An example is the energy control system of our body. The system is robust against unstable food supplies or infections, but fragile against unusual mutations such as high-energy content food or low-energy utilization lifestyle[3].

Biological robustness plays an integral role in survival which can be roughly classified into (i) adaption, i.e being able to cope with changes in the external environment; (ii) a level of insensitivity to small changes in values of the parameters that dictate underlying microscopic processes; and (iii) slowing down the rate of degradation of a system’s function following damage, as opposed to catastrophic failure [4].

Robustness is facilitated by various mechanisms in a system, such as redundancy, modularity, and decoupling. Many of these principles are also seen in engineering systems.

Redundancy can be seen in gene duplication, to protect against failure which may lead to deleterious mutations. In engineering, we see data-centers keep multiple backups of duplicates across multiple servers, which can achieve the same results if one system fails.

An example of modularity and decoupling in prokaryotes arises when a set of genes is regulated by the same transcriptional factor - which has a modular structure consisting of DNA binding domain, Activation Domain, and an optional Signal Sensing Domain. Modularity and decoupling are seen in programming, when a reusable chunk of code is treated as a module, which has singular functionality and can work independently. Its functionality can be exposed to other modules through API. All the modules working together run the entire application, and are decoupled from each other i.e we compartmentalize services of an entire application connected logically to implement the application.

Likewise, fragility can also be seen in computer systems as it can in biological ones. Consider a targeted attack on computer networks, with the star topology formation; the server, being at the centre of connecting nodes, is highly vulnerable and if breached, will have the tendency to break the system, similar to attack on single-celled eukaryotic cells resulting in deleterious consequences.

To avoid fragility, one architecture that has emerged is the “bow-tie” structure in which one side accepts possible inputs and the other generates outputs which are processed inside a central “core”. If the bow-tie structure were not there, generating a coordinated response to a range of stimuli would require a large number of individual controls instead. The core is highly interconnected and preserves much of its functionality. However, if a failure occurs in the core, it affects the entire system i.e the core shows fragility. Hence, robustness and fragility are inseparable.

Robustness and fragility being intertwined facilitates evolution. The balance between robustness at the core and the possibility of mutation due to system fragility helps in the evolutionary process which makes biological robustness an integral part of survival.

Citations-

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