BIOLOGICAL SYMMETRY AND INFORMATION-PROCESSING

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There seems to be a profound relation between the symmetry characterizing basic physical laws and that observed in biological structures. Two elementary symmetries of physical law are *i)* symmetry under translation, and *ii)* symmetry under rotation. Now the shape of many organisms seems to be related to *(i)* by the fact that all individuals of the same species often have the same shape, and to *(ii)* by the similarity of two or more sides of the organism's body. Is this affinity between the physical and the biological symmetries only coincidental or does it reflect a more profound relation?

An affirmative answer to the second option comes from the study of evolution as a computational process (Elitzur 1994, 1995). Central to this "proto-cognitive" model is the assertion that any population of self-replicating systems is capable, by the very dispersal of similar units in a certain environment, to extract, store and process information about that environment.

Within this framework, it is pertinent to examine the evolution of shape constancy and symmetry. As one follows the evolutionary tree onwards, from primitive unicellular organisms, through plants, to mobile animals, one encounters growing degrees of shape constancy and symmetry. We show that this evolutionary trend reflects growing cognizance of environmental invariants: The organism's shape should optimally adapt to those features of the environment that are not random, namely, to those environmental features that do not fluctuate from one site to another. Our hypothesis neatly reconciles two rival hypotheses concerning the biological role of symmetry: *i)* Møller (1992) argued that females' preference for symmetrical males, observed in swallows, reflects preference for healthier males, while *ii)* Enquist and Arak (1994) and Johnstone (1994) argue that this preference stems from the fact that symmetrical shapes are easier to recognize from various angles. In the proto-cognitive framework that we propose, both hypotheses are complementary in that they argue that evolution developes increasing abilities of recognizing invariant, as opposed to random, elements of the environment.

The above two symmetries appear also at another level, namely, the organism's sub-units. Interestingly, even non-uniform and a-symmetric organisms, such as plants, are comprised of highly uniform and symmetric units, such as leaves. Why do trees possess uniform and symmetric leaves? Branches grow more intensively towards the more illuminated side of the plant, thus being non-uniform and asymmetric. Why then not the leaf itself? True, symmetric and uniform leaves require smaller genetic programs for their production, but the fact that there are asymmetrical and non-uniform leaves shows that this explanation alone does not suffice. We therefore turn to information theory in search of a more appropriate answer.

Leaves are the main food resource of many insects and larvae. Luckily for the trees, many birds feed on insect larvae. The tree thus ought to inform the birds which of its leaves is harassed by the pests. Could leaves' uniformity and symmetry enable the tree to do so? Three observations (Heinrich 1979, 1992, Heinrich and Collins 1983) support this hypothesis: *i)* When the shapes of tree leaves were artificially damaged, the insect-eating birds frequented these trees or leaves more than undamaged leaves or trees. *ii)* Some caterpillars nibble the leaf margins in such a way that its shape is maintained, thus making it harder for the birds to locate the damaged leaves. *iii)* Many oak species, whose leaves are neither uniform nor symmetric, seem to be immune to leaf-eating pests. Notice that Møller's (1992) abovementioned hypothesis is complementary in this respect: Symmetry in birds is taken as an indication of well-being. Shmida (1992) suggested that flower symmetry is similarly correlated to high amounts of sugar.

Leaf uniformity and symmetry are thus efficient means of information transmission between the plant and other organisms. Could they also enhance information processing within the plant itself? We would like to suggest an affirmative answer, based upon the following observations. The leaf changes its angle throughout the day so as to get maximum sunlight. In order to best function as an "antenna," it must be symmetric in relation to the source of the radiation. It is the comparison between the light absorbed by the leaf's right and left halves that enables locating the source. Hence, identical halves would best perform this task. The explanation for the leaves' uniformity is similar. The formation of trunk and branches poses many demands to the tree: overcoming gravitational forces, optimal exploitation of light, avoidance of intersection between the brances, etc. Also, it consume much more resources than the formation of the small, short-lived leaves. Now leaves, besides fulfilling their known photosynthetic goal, are also capable of affecting the tree so as to grow towards those directions where light is abundant. Therefore it is vital for all leaves to be uniform and symmetric: Only then can the tree average all the environmental signals sensed by all the leaves, so as to grow the optimal shape. One way to test this hypothesis is to artificially affect leaves to have irregular forms and see if this affects the normal formation of the branch on which they grow in comparison to control branches.

There is an ethological analogue to this presumed mechanism: Increasing evidence suggests that flocking behavior among social animals enables the herd to reach optimal desicions by averaging all the individual movements (Deneunbourg *et al.* 1991; Kerlinger 1989).

The hypothesis that uniformity and symmetry serve information processing purposes rests on a principle well-known from information theory: Any medium or channel that stores, transmits or processes information must be in a low-probability state, i.e., highly ordered. Such, e.g., are the unexposed film or the clean writing-letter. The calibration of measuring instruments creates a low-entropy state in which the instrument is maximally unbiased and thus able to optimally receive incoming signals.

Uniformity and symmetry meet these very purposes. By growing a myriad of leaves that have the same shape and whose two sides are identical, the tree performs a very efficient form of measurements, comprised of numerous and repeating measurements that are later compared. Similarly, in order to notice local asymmetries in the environment, the leave itself must be symmetric in the direction measured. Leaf uniformity and symmetry are thus akin to the basic idea of replicability in scientific experiments: In order to rule out local, random artefacts, the replicated experiment should use identical, calibrated and unbiased measuring instruments.

Indeed, in is by now commonly accepted that many biological systems, besides carrying out their main tasks, also constitute information-processing systems. For example, the blood system in the brain serves not only to transport nutrients and oxygen to the brain, but also to inform the brain about the body's temperature, chemical balance, etc. The introduction of information-theory concepts to biology is likely to provide many further insights into the physical foundations of life.

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