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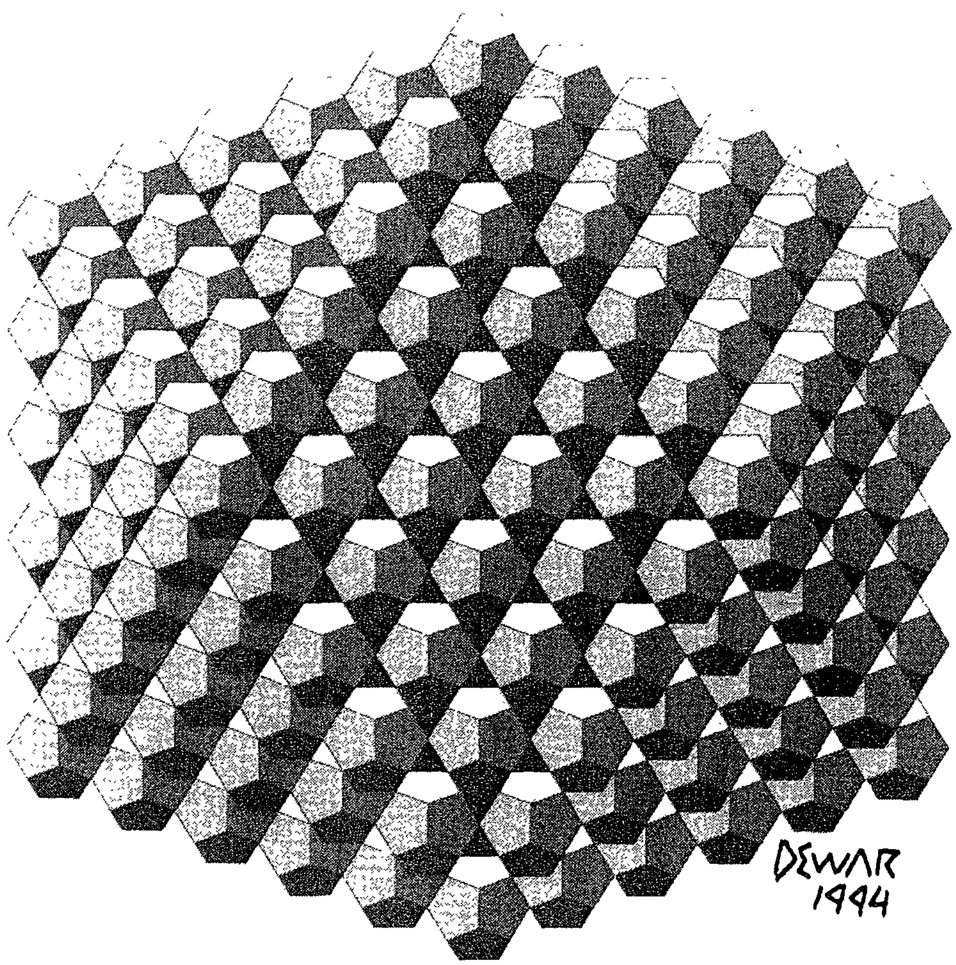

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SYMMETRY AND SYMMETRY BREAKING IN NATURAL AND ARTIFICIAL STRUCTURES

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In this contribution I'll dwell on a parallelism between the criteria adopted by nature in order to produce its **natural** structures and the criteria adopted by man to create his **artificial** structures.

To this end, we discuss first the clustering of an increasing number of atoms as a paradigm of the birth of the properties of a natural structure, and then the creation of tunes and their combinations in the musics, as a paradigm of the birth of one of the most suggestive and efficacious artificial linguistic structures.

Think to an atom, e.g. a sodium atom, Na. With its pointlike positive electric charge in the center and its spherical cloud of negative electrons gravitating around it, the Na atom is a structure extremely rich of symmetry. Two Na atoms bound in a diatomic molecule, Na_2, exhibit a lower symmetry than a single atom: in the isolated atom every diameter is an axis of rotational symmetry, while in the diatomic molecule only the axis connecting the two nuclei is an axis of rotational symmetry. Therefore a reduction of the original symmetry parallels the aggregation of structural (atomic) moduli in a structure This symmetry reduction is a characteristic feature of the formation of any ordered structure, whether natural or artificial

Nevertheless the Na atom and the Na_2 molecule don't have the thermal, mechanical or electric properties of a honest piece of sodium Many sodium atoms must come together in order to acquire these properties. A question arises: how many? Obviously as the number of atoms increases, the properties of the macroscopic body appear. However these properties emerge not with continuity, but indeed at intervals. Starting from an ideally symmetric gas of uncorrelated sodium atoms, in order to acquire macroscopic physical properties, clusters must be formed, containing "magic" numbers - 8, 20, 34, 40, 58, 92... - of constituent atoms. These numbers correspond to larger and larger polyhedral clusters. Only when the clusters become large enough so that the ratio of the surface energy to volume energy and the relative importance of surface tension get vanishingly small, the clusters lose their globular shape and the usual crystal structure, characterized by translational symmetry, emerges.

Aggregates with numbers of constituent atoms intermediate between two magic numbers are not sufficiently symmetric to build physically significant structures. While building larger and larger clusters, the practically absolute spherical symmetry of the individual constituent atoms is reduced at intervals, any interval marking a step toward the acquisition of the characteristic properties of the macroscopic body.

The process of symmetry breaking proceeds taking into account the nature of the constituent moduli and their interactions (think e.g. to the role of the dipole-dipole interaction of water molecules in the construction of the statistically selfsimilar dendritic ice structure on the windshield of a car parked open air during a winter night). The constraints originated by these interactions act as rules of the game. The systematics of the iterative addition of an atom after another, of a molecule after another in a crystal -or even in a living being- reflects itself in a form of invariance or symmetry: selfsimilarity. Actually selfsimilarity is found not only in crystals but also in clouds, forests, galaxies, leaves, feathers, rocks, mountains, torrents of water, and much else: if one looks at cauliflower it is hard to admit that fractals belong to artificial.

Summing up, while building its structures, nature breaks the symmetry, reducing it at intervals, and contextually increasing order or correlations. The game of organization of structures is thus the irreversible outcome of a delicate balance of symmetry and order: every step of symmetry reduction marks the outset of order and properties.

So far we have discussed the role of symmetry, as well as of symmetry breaking and order in natural structures and in their transformations.

However, mutatis mutandis, similar arguments apply to artificial structures.

Let us consider music.

The perfect symmetry of the silence could be broken, in principle, in several ways. However, in creating the acoustic alphabet of the musical language, man has built a periodic -and thus partially symmetric- system of tunes based on frequency ratios implying small integers: the structures of the Pitagorean scale confirms the Rainassance definition of music as the "numerus relatus ad sonum", the number related to sound. Small integers are needed again in music -but also, incidentally, in the metric of poetry- in order to define the rhythms, associated to a discrete time translational invariance.

Examples of partially symmetric artificial structures abund in architecture, in visual arts and practically in all products of technology, including the most symbolic and representative of them, the trade marks.

The natural criterion to realize a meaningful artificial structure is thus to break the symmetry only partially.

Perhaps we have here a key for the interpretation of the ancient proverb from the oral Zen tradition:

True beauty is a deliberate partial symmetry breaking.

In conclusion, in the natural world, energy or symmetry criteria regulate the a priori hyperastronomic number of combinations of myriads of atoms in matter, and thus severely select the physically significant material structures. In the artificial world symmetry criteria regulate the a priori possible combinations of signs, masses, colours, or elementary moduli, and thus severely limit the aesthetically meaningful structures and their tranformations.

While producing its structures, nature obeys its rules, based on partial symmetry breaking. But, as Leonardo states:

"In fact man [...] shows himself to be a divine thing; for where nature finishes producing its species there man begins with natural things to make with the aid of this nature an infinite number of species"

In other words also man, who is part of the nature, obeys the rules of nature.

Probably the secret of the success of the scientist and the artist lies in their skill in identifying, applying, and at the right moment, breaking and changing the rules of their creative combinatorial game: these rules must be compatible with the interactions and correlations naturally occurring between the elementary moduli. The systematics of the iterative application of these rules insures the existence of residual symmetry in the resulting artificial structures. This symmetry, in turn, harmonically balanced with the order induced by the above interactions and correlations, provides the artificial structure with an aesthetic significance: after all, a system can be qualified as a structure when a harmonic balance of symmetry and order in it can involve our aesthetic emotions.

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