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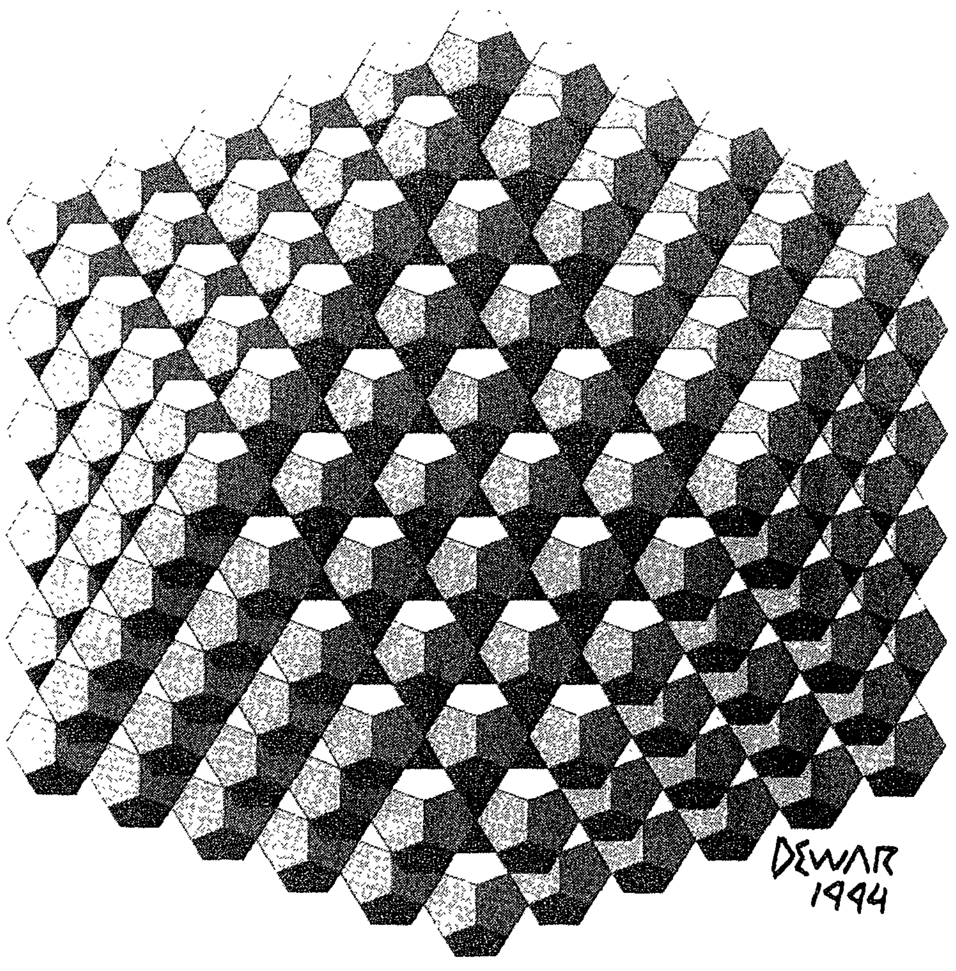


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# SYMMETRIES OF NATURAL AND ARTIFICIAL NEURAL NETWORKS

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Symmetry considerations play an important role in characterizing the structure and function of networks of neural elements. Here we survey and contrast symmetry issues involving a) biological neural circuits as studied by neuroscientists, and b) artificial neural networks.

## Natural Neural Networks

Neuroscientists have focused on describing the symmetries of brain structures and circuits, and on characterizing relationships between functional and structural asymmetries. Because of the irregular, variable nature of biological structures, a great deal of latitude is applied in calling two neural structures identical under symmetry operations.

*Symmetries*: Discrete translational symmetry is present in the segmental structure of the spinal cord, and to a lesser extent in the brain stem. However, most prominent is bilateral symmetry of neural circuits and structures. Bilateral symmetry appeared during evolution in association with orientability, directed movements and cephalization [7], and occurs in most invertebrates as well as vertebrates. Bilateral symmetry appears in both peripheral and central structures across an enormous variety of species [2], at both the macroscopic and microscopic levels. It has been suggested to underly our efficiency in visually recognizing mirror symmetries [1]. Using statistical/topological rather than geometrical criteria for equivalence under symmetry operations, one can characterize the structural symmetries of various cortical structures [3]. For example, the homogeneous cerebral cortex is invariant under translations and rotations (all proper isometries of the plane), while the cerebellar cortex is invariant only under translations and half-turns. Teleological explanations can be given for such differences [4].

*Asymmetry*: Far more effort has gone into characterizing the asymmetries of the brain than the symmetries, especially of the cerebral hemispheres (reviewed in [8,9]). The term asymmetry here refers to violations of bilateral symmetry. This work has been motivated by observations of prominent functional asymmetries of the two cerebral hemispheres (language, visuospatial processing, handedness, emotion, etc.) in the context of apparent structural symmetries. Mostly it has examined macroscopic anatomical asymmetries, e.g., differences in the sizes of cortical regions. However, differences in branching of neuronal process [16] and in the distribution of important neurotransmitters [18] have also been identified. These cerebral structural and functional asymmetries are poorly understood. They may represent an example of symmetry breaking, whereby initial quantitative structural asymmetries lead over time to qualitative functional asymmetries.

### Artificial Neural Networks

Neural models are computational/mathematical abstractions of the networks of neurons (brain cells) and their connections that exist in biological nervous systems. They differ from conventional computing methods in emphasizing highly parallel processing, active rather than passive memory elements, self-organization, and behavior as an emergent property rather than as a result of programming [14]. We consider two classes.

*Models of biological circuits* typically simulate neurobiological circuitry to examine hypotheses in neuroscience. The simulated network has a spatial organization, and there is a clear correspondence between model elements and neurobiological structures. Accordingly, work on these models must capture the symmetries existing in brain structures. This usually involves using circuits whose symmetries are simplifications of biological reality. For example, the approximate 0(2) symmetry group of the cerebral cortex or retina might be modeled by a two dimensional lattice with sixfold rotational symmetry elements [11,13]. More substantial group-theoretic methods are applied to classify animal gaits and to analyze symmetrically coupled neural oscillators that control locomotion [6].

*Models of intelligent behaviors*, developed in computer science, physics, cognitive psychology, etc., are further removed from biological reality and generally do not have a spatial organization. They model specific aspects of intelligence such as associative memory or pattern classification without concern for fidelity to brain mechanisms. Several symmetry issues arise in this context, such as recognizing symmetries in input patterns [5,17], analyzing functionality [12], use of symmetric weights [10], and symmetry breaking [15].

**Conclusion**

A wide range of symmetry issues arise in studying natural and artificial neural networks. In biological fields, the primary emphasis has been on determining structural *asymmetries* that may be the cause of observed functional asymmetries. In contrast, individuals developing artificial neural networks have primarily focused on how structural *symmetries* can be used to create or analyze specific model behaviors. The complementary work in these two areas suggests that there is fertile grounds for cross disciplinary interactions in examining symmetry issues.

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