Natural selection of visual symmetries

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Abstract. Implicitly, Wynn's (2002) target article starts from the transformational definition of symmetry. Unlike his suggestion, this traditional definition and the recent holographic definition are relevant to the discussion on the cognitive evolution of visual symmetries. These definitions reveal underlying properties and, thereby, they support the natural selection hypothesis. The holographic definition even agrees with an indirect test of this hypothesis.

In the course of evolution, our visual system became attuned to only a few of the innumerably many kinds of regularity in the world. A common idea in perception research is that each of these few regularities was selected because of its individual functionality — for the rest, these regularities are considered to be unrelated to one another. Remarkably, however, the visual regularities are practically the same as the regularities that are relevant in non-visual domains such as crystallography and molecular biology. This domain-transcending relevance suggests that there might be a more fundamental property that is characteristic for only these few regularities. In fact, two of such properties have indeed been found. First, the property of invariance under motion, as put forward in the traditional transformational approach (see, e.g., Palmer 1983). Another is the property of invariance under growth, as put forward in the more recent holographic approach (van der Helm & Leeuwenberg 1991; 1996; 1999).

As I elaborate in a moment, the transformational property relates to the external structure of regularities and is relevant in object recognition; the holographic property relates to the internal structure of regularities and is relevant in object perception (which precedes object recognition). Each of these two properties is, in a formal mathematical sense, characteristic for only a small set of regularities. The two regularity sets, thus defined, not only overlap largely, but also agree well with the regularities that are generally considered to be the visual regularities.

Although Wynn argued that such definitions are hardly required, he used the very specific transformational terminology by refering to the visual regularities as being symmetries that are reflectional, radial, rotational, or translational. Reflectional symmetry corresponds to mirror symmetry which, together with a kind of broken symmetry, forms the holographic regularity called bilateral symmetry — radial, rotational, and translational symmetries are variants of the holographic regularities called repetition and alternation.

Be that as it may, Wynn did not seem to realize that the transformational and holographic properties open the possibility that evolution has selected a central visuo-cognitive system that embodies one or both of these underlying properties. In other words, the existence of these underlying properties supports the idea that certain regularities became visual regularities by natural selection at the level of regularity-processing systems, rather than by, say, sexual selection at the level of individual regularities. Moreover, as I discuss next, favourable towards the survival of such a naturally selected system, are factors that run parallel to the transformational and holographic properties.

First, the transformational property of invariance under motion specifies visual regularities as being configurations which, if present in an object, yield the same retinal image after translations and rotations that let the object move as if it were rigid, even if it is not. This transformational invariance is a property of many flowers and crystals, for instance. The functionality of transformational invariance in object recognition is favourable towards its survival embodied in a regularity-processing system. That is, successful recognition of a transformationally invariant object, like a cube, can occur fairly independent of the viewpoint position taken by the observer (see, e.g., Enquist & Arak 1994).

Second, the holographic property of invariance under growth is the primary characteristic in van der Helm and Leeuwenberg's (1991) definition of visual regularity, and may be illustrated as follows. Living organisms generally grow such that their body shape remains basically symmetrical — that is, the symmetry structure is invariant under body growth. Similarly, the repetition structure of, for instance, a queue of virtually identical penguins remains a repetition structure when the number of penguins increases — that is, it is invariant under queue growth. The symmetry structure of a body grows cell by cell, and the repetition structure of a queue of penguins grows penguin by penguin, so that the holographic growth steps can be said to specify the constituent parts of each regularity.

The foregoing illustrates that holographic invariance relates to the internal growth structure of regularities — as opposed to transformational invariance, which relates to the external motion structure of regularities. Despite this difference, the functionality of transformational invariance in object recognition is also favourable towards the survival of a regularity-processing system that embodies the holographic property. After all, as mentioned, the holographic and transformational regularity sets overlap largely. By specifying the constituent parts of regularity, however, holographic invariance seems more fundamental: It specifies the intrinsic character of regularity, rather than just a transformational consequence of regularity. Furthermore, holographic growth seems a useful model of the way in which the visual system builds up its representation of regularities. Indeed, in contrast to the transformational approach, the holographic approach provides a fairly comprehensive explanation of the human perception of not only perfect but also imperfect regularities (see van der Helm & Leeuwenberg 1996; 1999).

For instance, the well-known phenomenon that mirror symmetry is the best detectable visual regularity by far (see, e.g., Barlow & Reeves 1979) is holographically explicable. Holographically, it is therefore no surprise that mirror symmetry intruded into various visuo-cognitive domains — including the domain of mate assessment, where a preference for more-symmetrical mates has been found (see, e.g., Møller 1992). Related to biological growth, these domains provide two further factors that are favourable towards the survival of holographic invariance embodied in a regularity-processing system. First, in scene perception in general, mirror symmetry is preeminently a cue for the presence of a living object. Second, in mate assessment in particular, the degree of (a)symmetry in an organism's body shape seems to be correlated with the organism's health in terms of genetic quality, developmental stress, and reproductive success (see, e.g., Møller 1990). Hence, the holographically-explicable high salience of mirror symmetry is functional in both domains.

Finally, several holographically explicable pecularities suggest that our far ancestors indeed perceived regularities in the same way as we do. First, depending on the context, modern humans may either overestimate or underestimate the amount of symmetry in an imperfect mirror symmetry (Freyd & Tversky 1984; van der Helm & Leeuwenberg 1996). Second, for modern humans, the detectability of a mirror symmetry is not strengthened but is weakened by salient substructures (Csathó et al., 2003). These pecularities do not seem to be explicable from sexual selection at the level of individual regularities. Hence, in sum, the holographic approach provides not only direct theoretical evidence but also indirect empirical evidence that the visual regularities emerged by natural selection at the level of regularity-processing systems.

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