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(100 word abstract)

Why Is Binocular Visual Space Distorted Compared to Physical Space ?

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We propose the ISLES model, a neural network model for the developmental learning of binocular visual space. When applied to the phenomena of Hering's horopter and the locus of perceived egocentric equidistance, this model provides a better qualitative explanation than the Luneburg theory. This model provides physical explanations for the differences among individual subject data, by accounting for the spatial distribution of the visual experiences for learning the perception. When the perceptions are classed via psychological scaling, their class logically determines the learning signal in this model. As a result, the same ISLES model can predict each phenomenon when a subject learns the physical loci under various conditions.

Preference for oral or poster presentation: Oral
1000 word (MAXIMUM) description of research.

From a psychophysical viewpoint, human binocular visual space is a distortion of physical space. For example, the perceived frontal parallel plane is actually curved in reality. This phenomenon is well known as Hering's horopter (H. Hering, Handbuch der Physiologie, 1879). A horopter curve is on a phenomenal frontal plane.

In this case, the cues for the perception of the frontal plane are the vergence angle and the bipolar latitude. Under these cues, the binocular visual space can be described as a perceptual space endowed with a rich geometrical structure, which according to Luneburg is a non-Euclidean Riemannian geometry of constant curvature (R.K. Luneburg, Journal of the Optical Society of America, 1950). In Luneburg's metric, a horopter curve is defined as a geodesic line on Riemannian geometry. The geodesic line is described with two individual constants and an invariant. However, the metric does not sufficiently explain why perceptual space is distorted.

A new hypothesis is proposed that perceptual space is distorted as a result of some physiological constraint that prevents complete learning of the perception, because the same phenomenon is observed regardless of the subject’s knowledge of its geometry.

From the viewpoint of psychological scaling, an invariant is always necessary in order to define a subjective line. This is the necessary condition for the nominal scale, which is the first class of the psychological scaling.
Also, the human perception process needs to be a function of the sensory cues and the invariant, because psychophysical measurement within the human perception process is always equivalent.

We provide a neural network model for the developmental learning of the perceptual space, which we call the ISLES model (Independent Scalar Learning Element Summation Model). The ISLES Model has learning constraints similar to a biological neural network. This model does not apply the back-propagation method but utilizes the Hebbian learning rule as a 3-layer Perceptron. In addition, the cells of the hidden layer are simple, with only one input signal. If these cells were more complex, the result of the learning would resemble the result of the back-propagation method. The ISLES model can only correctly learn the summation of each scalar function of input signals, so although its performance in learning arbitrary functions is mathematically incomplete, this incompleteness and the class of psychological scaling for learning made the curves of the frontal parallel horopter.

When the model has *n* independent input signals, it has *n* independent groups of simple cells. Each group is called a scalar learning element. This model has n scalar learning elements $\hat{f}_1(s_1),\cdots,\hat{f}_n(s_n)$ and only one summation unit for an output of a scalar value.

$$\hat{f}(s_1,\cdots,s_n)=\sum_{i=1}^{n}\hat{f}_i(s_i)+C$$

Using neural network learning methods such as steepest decent, after sufficient training, each function $\hat{f}_i(s_i)$ converges to an expected value, because each scalar learning element can learn any arbitrary scalar function.

$$\lim_{t\to\infty}\hat{f}_i(x)=\lim_{t\to\infty}E_{S_i}\left[f_{inv}\right]+C'$$

Here, S is defined as the whole domain for learning, and S_i is defined as a partial domain where $s_i=x$. The output of $\hat{f}_i(x)$ is determined as the expectation under the partial domain S_i.

In order to learn a frontal parallel plane, the training function need not be defined explicitly, but it must express the invariant for each frontal plane. In addition, the function must be monotonic to the depth in order to conserve the order. This is the necessary condition for the ordinal scale, which is the second class of the psychological scaling. The ordinal scale is necessary for the measurement of parallelity.

The individual shapes of horopters are represented as the distribution of points for learning under the domain of visual experience in the ISLES model. When the distribution of the learning points was homogeneous along the vergence angle and bipolar latitude, the results of the simulation for Hering's horopter predicted by the ISLES model are remarkably similar to the typical shapes of human horopters. Therefore, not only does the ISLES model provide a qualitative explanation of the phenomena of Hering's horopter as sufficiently as Luneburg's model, the distribution of learning points provides a physical explanation for the individual data as well.

In this result, the parameter δ for the depth of Luneburg's individual constants was slightly larger than the empirical average for humans. This leads to a distribution of learning points in the near area that is slightly greater than that of the human average.
This distribution in the ISLES model addresses the visual experiences of the human subjects in physical space, while the individual constants K and δ in Luneburg's model can be defined only in Riemannian space.

From this result, it seems that ISLES model can provide a better explanation in the physical sense than Luneburg's theory. Although Luneburg's theory provides a qualitative explanation of classical empirical phenomena, his theory has been less successful in quantitatively predicting individual data (T.

Indow, Journal of Mathematical Psychology, 1982), which has been taken as evidence against the presumed geometrical structure.

Some of these shortcomings, however, may also be attributed to psychophysical assumptions that do not depend on the geometry of visual space. The locus of perceived egocentric equidistance, for example, has been found to deviate systematically from the Vieth-Muller circle postulated by Luneburg (J.M. Foley, Journal of the Optical Society of America, 1966). The locus is always observed to be outside of the Vieth-Muller circle.

In contrast, the locus of perceived egocentric equidistance is easily defined under the ISLES model. The only difference from the case of Hering’s horopter is that an interval scale be imposed for the perception of the distances, which is the third class of the psychological scaling. After sufficient training, the perceived locus of egocentric equidistance could be extracted from the ISLES model simulations. The observed loci were consistently found outside of the Vieth-Muller circles.

This result means that the same ISLES model can generate both the phenomenon of Hering's frontal parallel horopter and the locus of egocentric equidistance when it learns the physical loci under psychological scaling. Based on these facts, it is confirmed that the ISLES model can provide a better qualitative explanation of the distortion of visual space than the Luneburg theory.

Preference for oral or poster presentation: Oral