Some General Grouping Principles: Line Perception From Points As An Example

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Abstract

Human vision has marvelous ability in grouping a set of points with finite distance in between to form coherent line contour perception. This paper first suggests some general principles for computing perceptual organization and then presents a model to group points into line contours. The grouping factors arise at two levels. At the first level, grouping factors are identified as direct point-point interaction and orientation interaction. Point-point interaction is short-ranged and homogeneous. Orientation interaction is locally oriented and mediated by local visual context. At the second level, grouping factors are global geometric binding effect arising from geometric redundancy reduction. Line perception is then generally formulated as combinatorial optimization. Since it includes local, global interactions and local context effects, the model may capture partially grouping ability of human vision systems.

1. Introduction

In recent years, visual grouping seems to arouse much research interest in visual neuroscience, visual psychophysics and computer vision. Neuroscience and psychophysics lead to the following findings

1 Some perceptual grouping processes are primarily bottom-up processes and can arise in the visual cortex as early as the V1[1][2].
2 There is a hierarchy in the grouping processes. At the low level of the hierarchy, there are many local grouping factors; at the high level, there may be global grouping factors[3][4].
3 Local visual time-spatial, spatial context plays important roles[5][6].

It seems that researchers in computer vision don't like to refer to these recent findings. Many grouping algorithms have been developed, for example[7][8][9], just as a few of them. These grouping algorithms are quite different from each other, not only in the computational techniques but also in types of organizations to compute. Almost all of these approaches, with [9] as an exception, are at the level of algorithm: they address how to do the grouping process but don't explain why some low level features should be grouped to form some organizations. In this sense, they are incomplete. Also it is quite difficult to evaluate the performance of these algorithms. Until recently, a comparison of three very effective grouping algorithms has been made[10].

This paper first suggests some general principles for computing perceptual organization and then presents a model to simulate an extreme case of perceptual organization: grouping a set of points with finite gaps in between to form the coherent perception of line contours.

2. Some General Principles

Referring to the recent findings in neuroscience and psychophysics, we suggest the following general principles for computing perceptual organization

1 Identifying grouping factors quantitatively. Grouping factors may arise at different levels of hierarchy, or from different visual modalities.
2 Identifying possible interaction of these grouping factors.
3 Including mediation of local time-spatial context.
4 If possible, putting grouping in the context of some visual tasks.

In practice, we can simplify these principles by referring to one, two or three of these principles. Of course, the first one is the most fundamental. In fact, almost all of present computational algorithms only refer to the first one.

In what follows, we are interested in an extreme case of grouping in human vision: grouping a set of points with finite gaps in between to form a coherent perception of line contour. Grouping is really critical to this perception.

We identify the grouping factors at four levels: local direct factors, global grouping factors due to geometrical arrangement of a chain of points, global grouping factors due to higher structures formed by the points, and global grouping factors due to functional or semantic meanings of the structures formed by the points. We also include the effects of local visual context on the local grouping factors. The global grouping factors are much less affected by the local context. But at this stage we can only formulate the first two kinds of grouping factors.

3. Direct Interactions

Let's consider first the local grouping factors. We call them local point-point interaction and orientation interaction. Point-point interaction is simply proposed as (See *Fig*. 1(left))

$$V_p = -W\,exp\left(-\frac{x^2}{2\sigma^2}\right) \quad (1)$$

x is the distance between two points. W>0 is a constant. Orientation interaction is suggested as (See *Fig*. 1(right))

$$V_o = -J\Phi\left(f\left(x_{\parallel}, x_{\perp}\right) + f\left(y_{\parallel}, y_{\perp}\right)\right) cos(\theta) \quad (2)$$

θ is the turning angle. $f(\bullet,\bullet)$ is an anisotropic shape function. Φ is a spatial smoothing factor related to local statistics of point-point connection. $cos(\theta)$ is dipole interaction representing orientation tuning. J>0 is tuning strength. We choose the shape functions as

$$f\left(x_{\parallel}, x_{\perp}\right) = exp\left(-\frac{x_{\parallel}^2}{2\mu_{\parallel}^2}\right) exp\left(-\frac{x_{\perp}^2}{2\mu_{\perp}^2}\right) \quad (3)$$

Φ is in fact the context effect. Considering in 4 cases, we choose Φ=1, 1.5, 1.5, 0.5 individually. Case 1 is "clean limit": there are no other points in a proper window between the two points. Case 2 is "all inhibition": all orientations formed by point-point connection are inhibited in the window. In case 3, there is a coherent orientation, formed by point-point connection, different from the orientations formed by the considered points. Both case 2 and 3 lead to detectability enhancement. In case 4, there are more than one un-correlated orientations formed by point-point connection, which degrades contour perceptual saliency. The shape function and context effect are absent in usual theories. Also note that the orientation interaction contains explicitly the position coordinate and thus the interplay between V_p and V_o is included in a natural way.

4. Geometrical Binding Effect

If a chain of points are aligned on a line of constant curvature, then there is some geometrical redundancy with the chain. Due to the redundancy, two points separated by a finite distance are correlated, and thus there is grouping tendency between them. Thus we suggest geometrical binding energy for the set of points[9]

$$B_1 = \left(p - q \times |c|^{2\phi}\right) \times \left(\mu L^{\alpha} - L\right) = \left(p - q \times |c|^{2\phi}\right) \times L\left(\mu L^{-\beta} - 1\right) \quad (4)$$

p>0, q>0 are constants. L is the length of the point chain. c is the curvature. ϕ, α are exponents. β=1-α. We set 0<α<1, 0<ϕ<1, 0<β<1 and choose proper length unit and short-distance cut-off to ensure that $p - q \times |c|^{2\phi} > 0$, $\mu L^{-\beta} - 1 < 0$. So we always have $B_1 < 0$. Which means that the geometrical binding effect is always attractive. Since the binding effect is associated with the whole emergent line contour, it's a global effect. Note that B_1 is designed in such a way that it has the following two important properties

$$\frac{\partial B_1}{\partial |c|} > 0;\ \frac{\partial B_1}{\partial L} < 0;\ \frac{\partial^2 B_1}{\partial^2 L} > 0 \quad (5)$$

The bigger |c|, the bigger B_1 and the smaller the binding tendency. The bigger L, the smaller B_1 and the greater the binding tendency. Thus, there is greater binding tendency with long, straight line contours formed by points.

If a chain of points are aligned on a line whose curvature changes greatly from point to point, we suggest the geometrical binding effect for this chain of points as

$$B_2 = 0 \quad (6)$$

In this case, there is no geometrical redundancy to be reduced. The local property of the line is much "unexpected" for vision system and thus all the changes should be represented. So the total geometrical binding effect of a chain of points is

$$B = \sum B_1 \quad (7)$$

Note that this geometrical binding effect is related to the curvature scale used and thus there is interesting connection between it and the curvature scale space in shape representation.

5. Line Contour Perception

Then the total energy of a line contour formed by a set of points is

$$H = \sum B_1 + \sum V_p + \sum V_o \quad (8)$$

We define the energy per unit length as the global saliency of the contour,

$$S_g = H/L \quad (9)$$

Where L is the total length of the contour. The smaller S_g (S_g<0) a line contour has, the more salient perceptually the line contour. Thus we select the line contours with small S_g as perceptually salient ones. Note this explains why a set of points should be grouped into line contour.

6. Some Experiments

In what follows we'll present two simple experiments.

Left in Fig.2 is a ϕ-like curve of points with random point noise. Given two proper start points, we can extract the ϕ, which is in fact composed of an ellipse and a straight line. p=1, q=20, ϕ=0.7, μ=1, α=0.4, W=1, J=2.5, σ=8, $\mu_{\parallel}$=8, $\mu_{\perp}$=4. The length of the gap between two neighboring points along the ϕ-like curve is 6. The number of noise points is 250. Note that there are no mistakes at the several crossing positions. Our theory in fact incorporates the Gestalt's good continuation rule.

The top left in Fig.3 is three curves consisting of points. The three curves intersect with each other. With the leftmost 10 points of each row as the start points, we can extract the contours as the first three with smallest s_g. In the decreasing order of global saliency are the straight line(with the smallest s_g <0), the parabola and the sinusoid. All the parameters are the same as above. The number of noise points is 200. This result is satisfactory. Note that there are no mistakes at the several complex intersecting positions.

We have also finished some other experiments and the parameters in all these experiments needn't change. From these experiments, we can see that by our computational model we can effectively compute coherent chains of points with finite gaps in between and with the presence of various kinds of noise.

7. Conclusion

In this paper, we refer to some recent findings of neuroscience and psychophysics on visual grouping to suggest some general principles for computing perceptual organization. To show how to implement these principles, we present a computational model to simulate an extreme case of perceptual organization: grouping isolated points into line contours. Since there are finite gaps between points and various noise, and the perception of line contours emerging from points is very vivid, perceptual organization is really critical in this extreme case. Our model incorporates both local and global grouping factors, local point-point interaction and orientation interaction, mediated by local visual context; and global geometrical binding effect. Some experiments show that the model can compute line contours emerging from points with finite distance in between very effectively.

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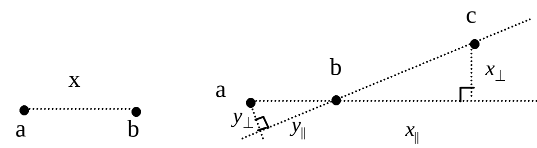

Figure 1. Left: Point-point interaction. Right: Orientation interaction.

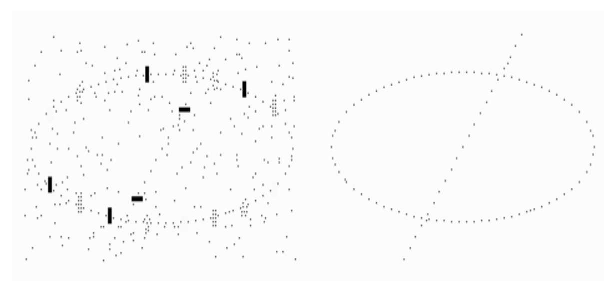

Figure 2. Left: A ϕ curve of points immersed in a background of point. Right: The ϕ extracted by our model.

Figure 3. Three curves composed by points extracted from the up-left input. In the decreasing order of saliency are the straight line, the parabola and the sinusoid curve.