Texture Perception

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Keywords:
visual perception, texture perception, spatial vision, edge detection, figure-ground segregation, visual cortex

Landy, M. S. (1996). Texture Perception. In G. Adelman (Ed.), Encyclopedia of Neuroscience. Amsterdam: Elsevier.

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As we parse the retinal image into different objects, a number of visual properties are used to distinguish figure from ground and one object from neighboring objects. These properties include luminance, color, relative motion, stereo disparity, and so on. Within a single surface there can be variation in surface reflectance, color or 3-dimensional orientation (surface roughness). These variations result in a textured retinal image. These textural variations can be regular (textiles, brick walls, honeycomb), random (forest floor) or in between (wood grain).

The occurrence of texture in a scene is useful in a number of ways. (1) The characteristics of a single texture may be used to identify the surface material as in knowing the type of wood from the grain (*texture appearance*). (2) When two objects (or parts of a single object) meet, an edge is formed. Identifying and localizing edges is a basic step in the figure-ground problem, and edges can involve a change in texture (alone, or in conjunction with a change of other surface properties). Thus, *texture segregation* can be an important component in identifying objects. (3) When a textured object is viewed, the geometry of perspective results in a distortion of the texture in the retinal image. Characteristics of the texture in the image may be used to infer properties of the 3D layout of objects and object shape (*shape-from-texture*). All of these capabilities have been studied both psychophysically and computationally, and there have been recent advances in understanding the neurophysiological basis for texture perception.

The area that has seen the greatest amount of effort has been in understanding the mechanisms of texture segregation. A considerable amount of research involves the use of synthetic textures involving texture elements (e.g. dots, line segments, small figures such as L's, T's and X's) that are placed on a uniform background in either a regular or a random fashion. Other work has used continuous-tone textures such as sums of sinusoids or filtered noise. The use of randomly placed texture elements was developed by Julesz and colleagues. An example of a result of this work is illustrated in Figure 1. Here, a region of randomly placed X's is easily distinguished from a background of L's. However, a foreground region of T's can only be distinguished with scrutiny. There is no visible texture edge or perceived textured object on a background even though the individual texture elements are easily discriminable.

The work of Julesz and colleagues led to a number of different theoretical positions on which pairs of textures will segregate easily. Their early work led to the conjecture that observers were sensitive only to differences in the 1st- and 2nd-order statistics of constituent textures. However, counterexamples to this conjecture have been found. Difficulties with this entire line of reasoning have been pointed out recently by Yellott, as the statistics to be compared were not those of the presented texture patterns, but rather of the ensembles from which they were drawn (because iso-3rd-order images are, in fact, identical images). The appearance of these counterexamples led Julesz to an entirely different, feature-based theoretical approach. The basic features or ‘‘textons’’ are defined as required by the empirical results, and include elongated blobs and line endings or terminators. Texture segregation was proposed to result from differences in the characteristics of the blobs (number, length, orientation, etc.) and number of terminators in the constituent textures.

A number of investigators have recently proposed computational models of texture segregation with a common form: a set of linear spatial filters similar in form to cortical simple cells, a pointwise nonlinearity, and further linear spatial filtering (which can result in responses similar to those of cortical complex cells). These models convert a difference in texture into a difference in response magnitude, allowing the texture edge to be enhanced and detected by conventional edge detection methods. The form of the models is inspired by neurophysiology. It has become a standard model in vision science that has unified the study of texture with other areas of spatial vision. Similar models have been applied to visual motion analysis as well. Because the models are implemented as computer algorithms, they may be applied to both pen-and-ink textures of the sort used by Julesz as well as continuous-tone and natural textures. They have been successful at modeling a variety of texture segregation phenomena such as the effects of texture element shape, size and spacing (Figure 2).

A number of different issues have been important in the recent texture literature. First, there are a number of different tasks that can be used to evaluate the perception of texture. At the same time that Julesz was studying texture segregation with images of randomly placed texture elements, Treisman looked at the ability of observers to find a single element (a ‘‘target’’) on a background of varying numbers of other texture elements (‘‘distractors’’). There are a number of similarities in the results of texture segregation, visual search, and other paradigms (e.g. texture-defined object discrimination) using identical texture element pairs. But, it is not always true that texture element pairs lead to easy search if and only if they lead to good texture segregation. Even with a fixed pair of texture elements, there are often asymmetries in performance depending on which element is the target (or composes the foreground texture) and which is the distractor (or background). In addition, the type of texture elements used is only one component of good performance on texture segregation tasks. The placement of the texture elements (at random, or in a set pattern) is also important, leading some researchers (notably Beck and colleagues) to concentrate on properties that lead to perceptual grouping of texture elements.

We have concentrated on a review of perceptual texture segregation research, but texture is useful for other purposes and has been studied in other communities. The distortion of projected texture with changes in viewing geometry is a cue to surface geometry as discussed, for example, by Gibson. It has been noted that perception of shape from surface texture is a response to several cues including changes in texture element density, size and shape. In computer vision, texture segregation (for object recognition), texture appearance (e.g. for identification of land usage in satellite photographs), and shape-from-texture have been studied extensively. In neurophysiology there has been a great deal of interest in relating the luminance edge responses of neurons (especially in cortical areas V1 and V2) to their responses to texture-defined edges (and other ‘‘illusory contours’’). Recently, this has been related to neural responses to stimulation outside of the traditional receptive field.

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FIGURE LEGENDS

1. Texture segregation. Notice that the region of X's segregates easily from the background of L's whereas the region of T's can only be perceived with item-by-item scrutiny.

2. Response of a simple nonlinear filtering model of texture segregation to the stimulus of Figure 1. The stimulus was filtered by an isotropic, bandpass, linear spatial filter (a difference of Gaussians). The resulting image was subjected to a pointwise nonlinearity (x^2), and then blurred. Note how this turns the textural difference that segregates easily into a difference in response strength (Bergen and Adelson, 1988).

Figure 1

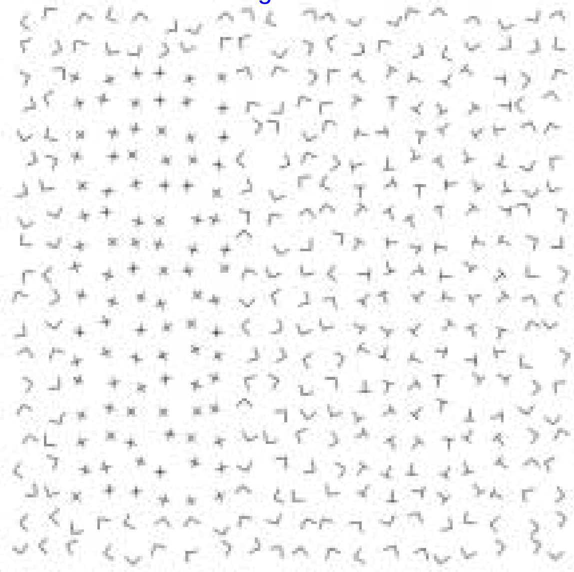

Figure 2