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Form and Texture in Hierarchically Constructed Patterns

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Perceived organization of hierarchically constructed patterns was investigated through similarity judgments and a verbal description task. The number of elements and their sizes relative to the configuration were varied in a series of five experiments. The results show that in patterns composed of a few relatively large elements, the elements are perceived as individual parts of the overall *form* and are perceptually salient. Increasing the number of elements and/or decreasing their size results in a perceived unified form associated with *texture*, representing the structural properties of the elements as a group. In the latter case, the perceptual salience of the individual element decreases and the global form (or sometimes the texture) dominates perception. These findings suggest that the perceptual levels arising from global configuration of local elements may not correspond directly to these two geometrical levels in the stimulus domain as much previous work on "global versus local" processing has assumed. Rather, the mapping of the two independent geometrical levels into meaningful perceptual levels depends critically on the number and relative size of the elements, thus changing the perceived organization of the whole pattern.

An important perceptual issue concerns the nature of the basic units of perception. In psychology this question can be traced back to the controversy between two schools of perceptual thought: Structuralism and Gestaltism. Structuralists have held that the basic units of perception are independent local sensations that can form extended units only through learning and experience. Gestaltists, in contrast, have seen the primacy of extended units simply as a result of a certain type of stimulus structure affecting an organized perceptual system. A basic tenet of the Gestalt view of perception is that a specific sensory whole is qualitatively different from the complex that one might predict by considering only its parts. The quality of a part is determined by the whole in which this part is integrated. Thus, "local sensations and all their relations will not have a real shape before it is segregated as a visual whole" (Köhler, 1971, p. 162).

Although the basic flavor of the structuralist approach has been retained in many current models of perception (e.g., LaBerge, 1973; Rumelhart & Siple, 1974; Treisman, 1969), several theorists have recently proposed that perceptual processes proceed from global structuring toward more local, detailed, analysis (Broadbent, 1977; Navon, 1977). The decomposition of a visual scene is viewed as a hierarchical network of subscenes interrelated by spatial relationships (e.g., Palmer, 1975, 1977; Winston, 1975); it is claimed that higher order properties are processed first, followed by analysis of lower order properties.

This hypothesis has been experimentally tested by studying the perception of heirarchically constructed patterns in which larger figures are constructed by suitable arrangement of smaller figures. Throughout this article, we use the following terms to describe the structure of such stimuli: *Pattern* refers to the entire stimulus figure, *local elements* to the smaller figures that make up the pattern, and *global configuration* to the larger figure constructed from the local ele-

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ments. Thus, global configuration does not refer to the local elements at all, whereas pattern refers to both levels at once. We conceive of these two levels of pattern structure—global configuration and local elements—as geometrically independent. Whether or not they are perceptually independent is another matter.

By a set of converging operations, Navon (1977) demonstrated the perceptual priority of global configurations. The main finding was that conflicting information between the local and global levels (e.g., a large H made up of small ss) had an inhibitory influence on responding to the local letter in a Stroop-like interference task, but not to the global letter. Navon interpreted these findings as evidence for the inevitability of global precedence in visual perception.

However, studies done by Kinchla and Wolf (1979), using a target search paradigm, Pomerantz and Sager (1975), using Garner's (1974) sorting paradigm, McClean (1978) and Martin (1979), using the interference paradigm, and Hoffman (1980), using both the interference paradigm and the target search paradigm, seem to conflict with Navon's claims. Depending on variables such as the overall visual angle of the stimulus (Kinchla & Wolf, 1979), brightness (McClean, 1978), number and spacing of the local elements (Martin, 1979; Pomerantz & Sager, 1975), and clarity (distorted vs. undistorted forms; Hoffman, 1980), the local element rather than the global configuration can be favored perceptually.

Although differences in task variables may account for some inconsistencies in the results of global–local studies, we question some assumptions underlying much of this research with hierarchical stimuli. In particular, it seems to have been frequently presupposed that there are two perceptual levels corresponding directly to the global configuration and local elements, and that the critical question is which level gets processed first. The assumption that two independent perceptual levels correspond directly to two independent geometrical levels may be true in some cases and false in others, however. Thus, some clear notion of how hierarchical patterns are organized perceptually is an important prerequisite for asking meaningful questions about processing mechanisms.

We take as our starting point a phenomenon discovered by Goldmeier (1936/1972) in studies of visual similarity. Using patterns composed of different numbers and relative sizes of local elements, Goldmeier found that *proportional enlargement* of a figure (that is, an enlargement in which the sizes of both the global configuration and the local elements are increased equally by uniform dilation) looked more similar to the original figure only when the original figure was composed of a few elements that were large relative to the global configuration. When the figure was composed of many elements and/or the elements were relatively small, a particular sort of unproportional enlargement looked more similar—one in which the global configuration was enlarged but the measurements of the elements were unchanged. Goldmeier suggested that the latter type of stimulus produces phenomenal separation between the overall *form* and the *material* from which the form is constructed. This separation disappears in the organization of a pattern composed of a few relatively large elements. When the figure is composed of a few relatively large elements, they are perceived as individual parts of the overall form. When the figure is composed of many elements and/or they are relatively small, the elements are relegated to the role of material or, in other words, serve to define *texture* and do not interact with the form of the figure.

The distinction between patterns in which the elements are perceived as individual parts of the overall form rather than as texture may resolve some of the inconsistencies in the global–local studies. The distinction also may facilitate understanding the perception of the "local" and "global" aspects of a pattern. Goldmeier's (1936/1972) work suggests that the number and relative size of the elements are important factors in determining the role of the elements in a pattern. The present experiments investigate the effects of these two factors on the perceptual organization of patterns composed of elements through similarity judgments and a verbal description task.

Experiment 1

Experiment 1 parametrically investigated the phenomenon discovered by Goldmeier (1936/1972). Subjects were presented with a standard figure and two comparison figures. All figures were composed of elements. The number of elements used to construct the standard figure was varied. One comparison figure was a proportional enlargement of the standard figure (i.e., the overall figure and the elements were proportionally enlarged). The other comparison figure was an unproportional enlargement having the same overall size as the proportional enlargement but containing elements whose size and spacing were the same as in the standard figure. We expected that the probability of choosing the unproportional enlargement would increase monotonically as the number of elements increased due to greater separation between form and material.

Method

Subjects. Seven females and five males ages 21–36 with normal vision volunteered to participate in the experiment.

Stimuli. There were 24 stimulus triads. Each stimulus triad was presented as three black patterns on a white index card (22 cm × 13 cm). The triad contained a standard figure on the top and two comparison figures side by side below the standard. Each pair of comparison figures consisted of a proportional enlargement and an unproportional enlargement of the standard figure. One set of the stimulus triads is shown in Figure 1. The enlargement was in the ratio of 1:1.6. Half of the stimulus triads consisted of squares made up of small squares, and the other half consisted of triangles made up of small triangles. In the standard figure there were 1, 4, 9, 16, 25, and 36 elements for the squares and 1, 3, 6, 10, 15, and 21 for the triangles. Subjects viewed the cards from approximately 60 cm, although this varied from subject to subject in an uncontrolled fashion. At this distance, each individual element subtended .29° (degrees of visual angle); the global configurations subtended .29°, .95°, 1.34°, 1.53°, and 2.29° in the increasing-number conditions. In half of the stimulus triads for each type of figure the positions of the two comparison figures were reversed.

Procedure. Subjects were asked to give their immediate and spontaneous impression about which of the two comparison figures looked more similar to the standard figure. The subject sat in front of a table and saw one card at a time. Each subject gave a similarity judgment for each of the 24 cards. The order of the cards was random over subjects.

Design. The three factors of the design were number of elements (6 levels); figure (square, triangle); and subjects. All factors were combined orthogonally except that the value at each level of the factor of number was different for the two types of figures.

Results and Discussion

Each response was scored as 1 if the unproportional enlargement was chosen and as 0 otherwise. Probabilities of choosing the unproportional enlargement as a function of the number of elements for each type of figure are shown in Figure 2.

Since each subject gave two responses to each combination of number and figure, a score of 0, 1, or 2 was assigned to each subject, and a three-way analysis of variance (ANOVA) was performed. The analysis treated the number factor as nested within the figure factor. The overall probability of choosing the unproportional enlargement was significantly higher for the squares than for the triangles, $F(1, 11) = 7.91$, $p < .01$. The effect of number of elements was significant for both figures: for squares, $F(5, 55) = 25.41$, $p < .001$; for triangles, $F(5, 55) = 7.10$, $p < .001$.

A closer inspection of the data by binomial tests showed that when the number of elements embedded in the square was 1 and 4, the probability of choosing the proportional enlargement was significantly higher than the probability of choosing the unproportional one ($p < .001$ and $p < .05$, respectively). When the number of elements was 9 or more, the probability of choosing the unproportional enlargement was significantly higher ($p < .01$ for 9 and 16 elements; $p < .001$ for 25 and 36 elements). With the triangles, the region of transition from proportional to unproportional enlargement was larger: The probability of choosing the proportional enlargement was significantly higher for 1- and 3-element figures ($p < .001$ and $p < .01$, respectively), whereas the opposite holds only for 21-element figures ($p < .05$).

The present experiment replicates Goldmeier's effect. When the figure was composed of a few relatively large elements, proportional enlargement was favored. Moreover, the response to the few-element patterns was the same as to the 1-element pattern, where there was no structural separation between the local element and the global configuration. When the number of elements increased, the comparison figure in which the overall figure was enlarged but the

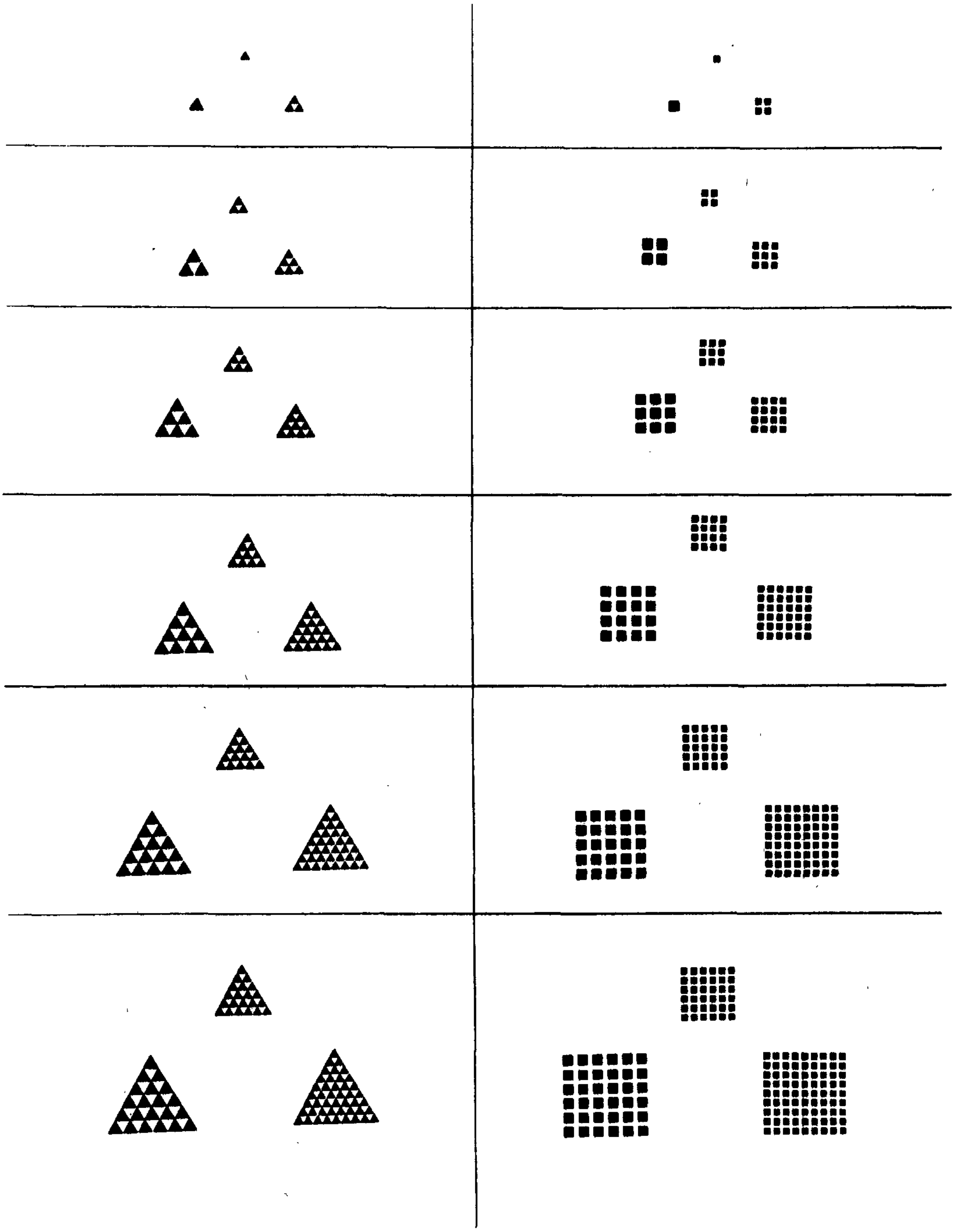

Figure 1. The set of stimulus triads in Experiment 1. (Another 12 stimulus triads were identical to the ones presented here, except that the position of the comparison figures was reversed.)

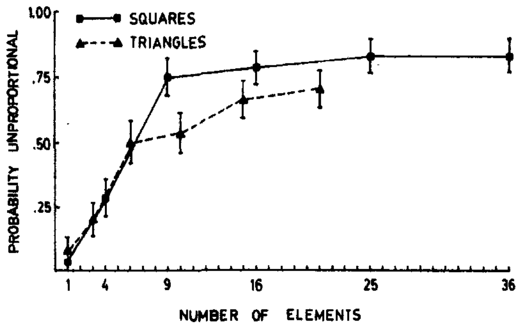

Figure 2. Results of Experiment 1: The probabilities of choosing the unproportional enlargement of the standard figure as a function of the number of the elements in the standard figure. (The error bars represent plus and minus 1 *SE*.)

measurements of the elements were kept unchanged (i.e., the unproportional enlargement) was judged more similar to the standard figure. Note that keeping the elements' measurements unchanged refers to both the elements and their interrelations (i.e., size and distance). Since both enlargements preserve the global configuration (transposition in size does not affect the perceived shape), the switch from choosing the proportional enlargement to choosing the unproportional one can be interpreted as reflecting the appearance of *material* (Goldmeier 1936/1972) or *texture*, a phenomenal quality representing the structural properties of the elements as a group rather than as individuated entities.

Thus, when the pattern is composed of a few relatively large elements, the elements are perceived as individual parts of the overall form. When the number of elements is rather large, there are two phenomenal qualities: form and texture. Both are important for the impression of similarity. The element loses its function as an individual part of the form and serves to define texture. Its properties contribute to the emergent properties of the elements as a group—that is, textural properties such as density, regularity, and orientation—but are not represented specifically as figures in and of themselves.

The difference between squares and triangles regarding the appearance of the impression of texture (as indicated by choosing the unproportional enlargement) might be due to the fact that the white spaces between the small triangles are themselves triangles (see Figure 1) and their number is smaller. If they are perceived as *figure* (rather than *ground*) the parametric difference between the square and the triangle conditions diminishes.

It should be noted that since we used forced-choice similarity judgments, the similarity judgments did not yield information about the degree of the similarity of a particular comparison figure to the standard. However, all comparison figures were proportional and unproportional enlargements of the standard; the only manipulated factor was the number of elements. Thus, the present approach was appropriate for studying the main question of interest in the present study—namely, how increasing the number of elements affects the choice between the two comparison figures. The same line of reasoning also holds for the three experiments that follow.

Experiment 2

The interpretation of the previous findings in terms of the function of the element in a pattern has implications for the relative salience of the local elements versus the global configuration. When the pattern is composed of a few relatively large elements, the elements are salient as figural parts of the overall form. When the number of elements increases and they become part of the texture, the global configuration is more salient than the individual elements.

The second experiment tests this hypothesis. Subjects were presented with a standard figure and two comparison figures, each consisting of a global square or triangle made of local squares or triangles. In the *same-configuration* comparison pattern, different elements were arranged in the same configuration as the standard figure. In the *same-element* comparison pattern, the same elements as in the standard figure were used but were arranged in a different configuration. The number of elements used to construct the standard figure was varied. If the elements are less salient when they are more numerous and relatively smaller, then the probability of perceiving the same-configuration pattern as more similar to the standard should increase as a function of the number of elements.

Method

Subjects. Twelve new subjects, eight females and four males ages 21–33 with normal vision, participated in the experiment.

Stimuli. There were 16 stimulus triads. Each stimulus triad was presented as three black patterns on a white card (15 cm × 13 cm) and contained a standard figure and two comparison figures in the manner described under the heading Experiment 2. The set of the stimulus triads is shown in Figure 3. In half of the stimulus triads the standard figure was a "square" made up of either squares or triangles. In the other half the standard figure was a "triangle" made up of either triangles or squares. In the standard figure there were 4, 9, 16, and 36 elements for the "squares," and 3, 10, 15, and 36 for the "triangles." Subjects viewed the cards from a distance of approximately 60 cm. At this distance the global configuration subtended about 1.9° in the different stimulus conditions. Each individual element subtended .76°, .48°, .38°, and .19°. Each type of comparison figure appeared equally often in the right and left position.

Procedure. The procedure was the same as in Experiment 1.

Design. The three factors of the design were number of elements (4 levels); configuration (square, triangle); and subjects. All factors were combined orthogonally. (Technically, the number of elements were not exactly equal for squares and triangles at Levels 2 and 3 of that factor, but they differed by only one element in each case.)

Results and Discussion

Each response was scored as a 1 if the same-configuration stimuls was chosen and 0 otherwise. The probabilities of choosing the comparison figure having the same configuration are shown in Figure 4 as a function of the number of elements embedded in the standard figure.

Since each subject gave two responses to each combination of number and configuration, the score 0, 1, or 2 was assigned to each subject. A three-way ANOVA (Num-

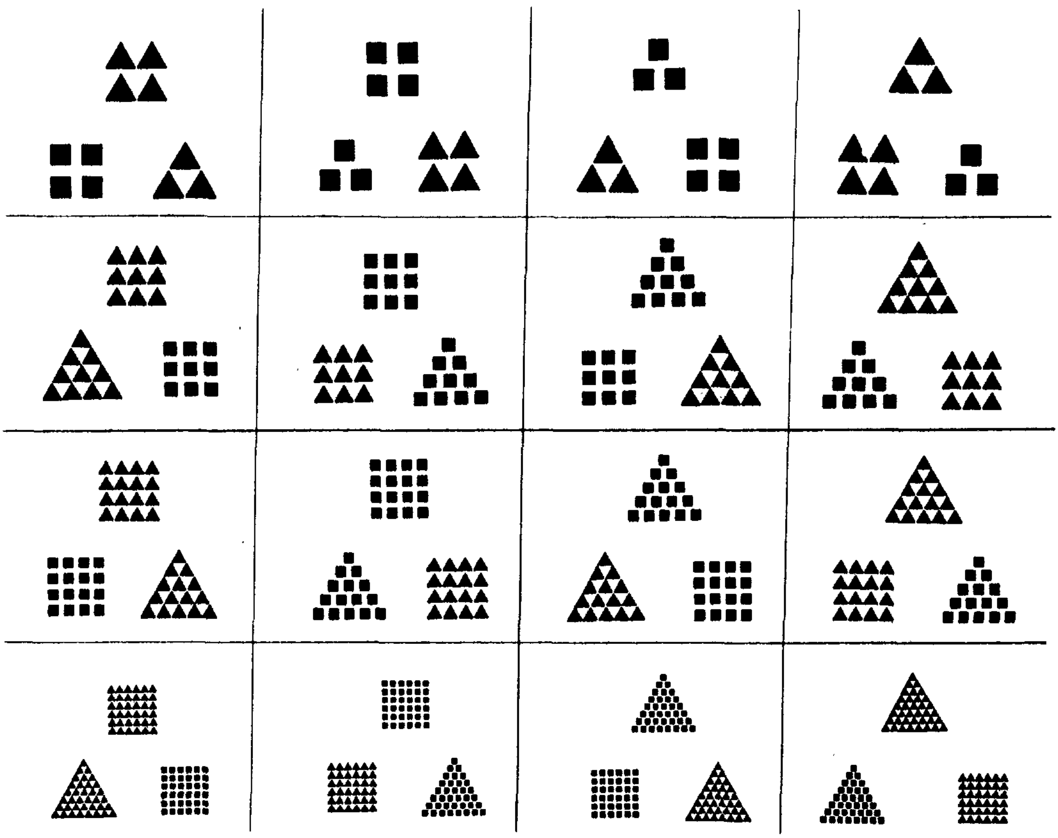

Figure 3. The complete set of stimulus triads in Experiment 2.

ber × Configuration × Subjects) was performed. The difference between the "squares" and the "triangles" ($F < 1$) and the Number × Configuration interaction ($F < 1$) were not significant. The effect of the number of elements was significant, $F(3, 33) = 10.82$, $p < .001$.

Closer inspection of the data by binomial tests showed that when the number of elements was 3 (triangle configuration) or 4 (square configuration), the probability of choosing the comparison figure having the same elements arranged in a different configuration was significantly higher than the probability of choosing the one having the same configuration composed of different elements ($p < .01$). When the number of elements was 15 (triangle configuration) and 36 (triangle and square configurations) the probability of choosing the comparison figure having the same configuration was significantly higher ($p < .05$).

The results of the present experiment support our hypothesis. When the number of elements increases, they are relegated to the role of defining texture (as indicated by choosing the unproportional enlargement in Experiment 1); the global configuration is perceptually more salient than the individual elements (as indicated by the similarity judgments in Experiment 2). Furthermore, the global configuration is phenomenally independent of its local constituents: Replacing the elements of the figure by other elements did not affect the perception of its overall form. As such the present experiment provides a converging operation to define the separation between overall form and the material from which the form is constructed. The finding that there was no local-to-global interference in a Stroop-like interference task in the case of inconsistency between the global shape and the shape of the local elements (e.g., an H made of Ss) for figures composed of many small elements (Kinchla & Wolf, 1979; Martin, 1979; Navon, 1977) is also consistent with this notion.

The results for the figures with a few relatively large elements showed the importance of the individual elements for making similarity judgments. However, the predominance of the elements does not necessarily indicate that the similarity judgments were based solely on the individual elements, since the actual global shape of the variant that supposedly had the same configuration was different. For example, the triangular configuration made of three relatively large triangles results in a "better" global triangle than the triangular configuration made of three relatively large squares (see Figure 3). An unpublished study by Lotery (Note 1) attempted to overcome this difficulty by using squares and rectangles with which it is possible to obtain similar global configurations while varying the local elements. The next experiment replicated her study following the same experimental design as in the present experiment.

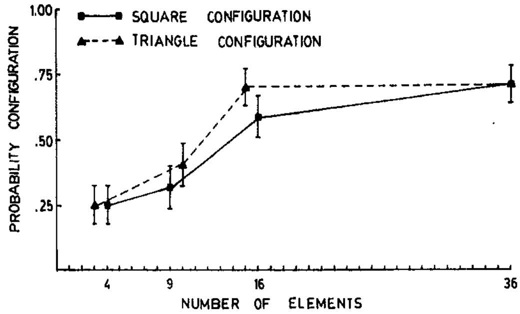

Figure 4. Results of Experiment 2: The probabilities of choosing the comparison figure having the same configuration as the standard figure, as a function of the number of elements. (The error bars represent plus and minus 1 *SE*.)

Experiment 3

Subjects were presented with a standard figure and two comparison figures. All figures consisted of a global square or rectangle made of local squares or rectangles. The use of squares and rectangles made it possible to minimize the confounding between the global outline and the local elements in patterns composed of a few relatively large elements. Thus, we will get a clearer picture of the importance of the individual elements in such patterns for the impression of similarity. In addition, the elements and their spatial arrangement were kept the same while varying the global configuration of many-element patterns. As a result global configuration was pitted against texture rather than against the individual elements as in the previous experiment. The question

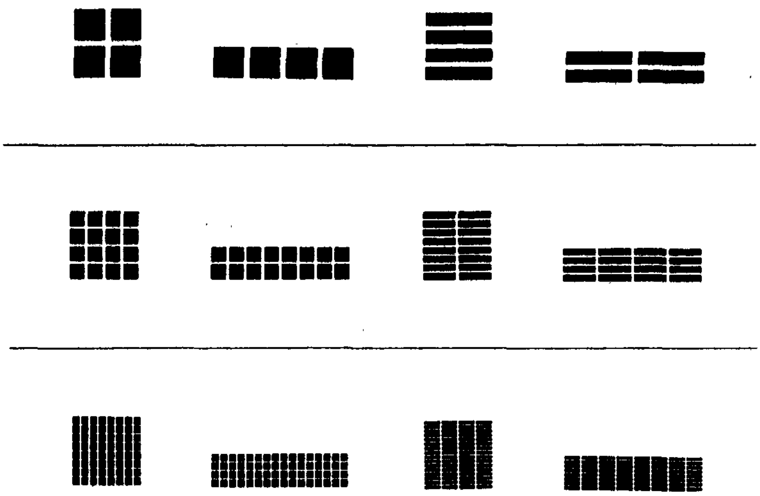

Figure 5. The set of figures from which the stimulus triads were constructed in Experiment 3.

was thus whether form or texture would dominate the impression of similarity in the many-element conditions of the present experiment.

Method

Subjects. Twelve new subjects, six females and six males ages 24–30 with normal vision, participated in the experiment.

Stimuli. There were 24 stimulus triads, constructed in the same manner as in Experiment 2. The set of figures from which the stimulus triads were constructed is shown in Figure 5. In half of the stimulus triads the standard figure was a "square" made up of either squares or rectangles. In the other half the standard figure was a "rectangle" made up of either rectangles or squares. In the standard figure there were 4, 16, and 64 elements. Subjects viewed the cards from approximately 60 cm. At this distance, the global square subtended 1.81° and the global rectangle subtended 3.81° in width and .80° in height. Each individual square element subtended .76°, .38°, and .19° in the increasing number conditions. Each individual rectangle element subtended 1.81° and .286°, .859° and .171°, and .38° and .057° in width and height respectively. In half of the stimulus triads for each type of figure the position of the comparison figures was reversed.

Procedure. The procedure was the same as in the previous experiments.

Design. The three factors of the design were number of elements (3 levels); configuration (square, rectangle); and subjects. All factors were combined orthogonally.

Results and Discussion

Each response was scored as a 1 if the same-configuration stimulus was chosen and 0 otherwise. The probabilities of choosing the comparison figure having the same configuration are shown in Figure 6 as a function of the number of elements.

Since each subject gave four responses to each combination of number and configuration, the score of 0, 1, 2, 3, or 4 was assigned to each subject. A three-way ANOVA (Number × Configuration × Subjects) was performed. The difference between the "squares" and the "rectangles" was not significant ($F < 1$), and the effect of number did not reach significance, $F(2, 22) = 3.40$, $p > .05$). The interaction between number and configuration, however, was significant, $F(2, 22) = 15.55$, $p < .001$.

Closer inspection of the data by binomial tests showed that when the standard figure was either a square or a rectangle composed of 4 and 16 elements and a square composed of 64 elements, the probability of choosing the comparison figure having the same elements was significantly higher than the probability of choosing the one having the same configuration composed of different elements ($p < .001$ for 4 and 16 elements in square and rectangle configurations; $p < .005$ for 64 elements in square configuration). When the standard figure was a rectangle composed of 64 elements, performance reached chance level ($p < .50$)

The present results for *few-element patterns* converge with and clarify those of Experiment 2. The preference for the comparison figure having the same elements as the standard figure was also obtained when the change in the global outline was minimized while varying the local elements. Thus it seems fair to conclude that the individual elements in such patterns are perceptually salient as indicated by their importance for the impression of similarity.

These results might suggest that in the case of a pattern made of a few relatively large elements, the elements are perceptually more salient than the global configuration. However, to take the results of Experiment 1 into account as well (i.e., the preference of the proportional enlargement in the case of pattern made of a few relatively large elements), an alternative interpretation seems more plausible—namely, that the elements are perceived as individual parts of the overall form. That is, there may be no phenomenal separation between the overall form and the elements.

At first glance the results for the *many-elements patterns* seem to contradict the hypothesis, supported by Experiment 2, that the form of many-element patterns is perceptually more salient than that of its individual elements. Increasing the number of elements in a square configuration did not affect the subjects' choices; although it had some effect in the expected direction when the standard figure was a rectangle, in both cases the same-configuration comparison figure was not the preferred one. However, consideration of the particular construction of the present stimuli shows that the present results do not necessarily contradict the above hypothesis.

In Experiment 2, the spatial arrangement of elements changed when the global configuration was varied. For example, in a square made up of squares, the square elements were arranged in a gratinglike fashion. When the same elements were used to construct a triangle, the square elements were arranged in a bricklike fashion (see Figure 3). Thus, the global form was pitted against the shape of individual elements; the results indicated the relative dominance of the global form. In Experiment 3, however, both the elements *and* their spatial arrangement were kept absolutely the same while

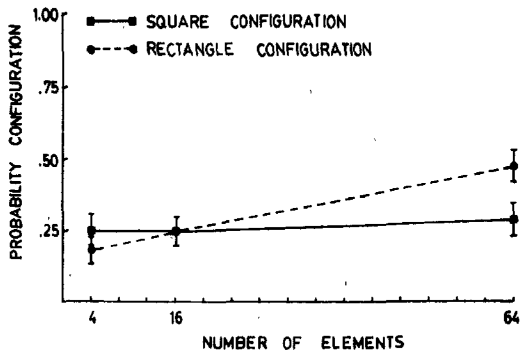

Figure 6. Results of Experiment 3: The probabilies of choosing the comparison figure having the same configuration as the standard figure, as a function of the number of elements. (The error bars represent plus and minus 1 *SE*.)

varying the global configuration in many-element patterns (see Figure 5, rows 2–3). It has already been suggested that keeping the elements and their measurements the same results in an identical impression of texture. Thus, in the many-element conditions of Experiment 3 the global form and the texture were pitted against each other. The results can be interpreted as indicating that texture was more important for the impression of similarity than the form, except when the standard figure was a rectangle composed of 64 elements, where the form seems to compete with texture. The strong impression of the texture in Experiment 3 also was revealed in a postexperiment inquiry. Subjects described the standard figure and the same-element comparison figure in the few-element conditions as having the same element shape, whereas in the many-element conditions they were described as being like gratings or pieces cut from the same cloth. The latter descriptions also suggest that textural properties rather than the individual elements attracted the subjects' attention in many-element patterns.

The difference between many-element rectangles and many-element squares that suggests the dominance of texture when the standard figure was a square and a competition between texture and form when the standard figure was a rectangle might demonstrate another instance of asymmetry in similarity judgments proposed by Tversky (1977) and Rosch (1975) (i.e., a rectangle is more similar to a square than a square to a rectangle).

In Experiment 3 as well as in Experiment 1, identical impressions of texture were obtained when the elements and their measurements were kept absolutely the same. Recent work on texture perception suggests that texture reflects crude information about the structural properties of elements. Beck (1967; Beck & Ambler, 1972) demonstrated that with respect to the dimension of shape, line–slope differences seem to be critical for texture discrimination. Julesz (1975) proposed that texture perception is determined only by first- and second-order regularities, those that can be registered by the frequencies of points and of oriented dipoles that constitute the perception of density and "compactness." Other work done by Pomerantz (1981) and Julesz (1981a, 1981b) suggests that although line–slope differences and order–statistics differences are important factors, they are not sufficient to explain all of texture discrimination. In any case, it is clear that current work on texture perception is consistent with our interpretation that the same-element stimuli in Experiment 2 differed in perceived texture, whereas those in Experiment 3 did not.

Taken together, the results of Experiments 2 and 3 suggest that a pattern consisting of a few relatively large elements is encoded as individual units in various spatial relationships to each other. When the number of elements increases, the pattern is encoded as a unified form associated with texture, representing the structural properties of the elements as a group. While global form of a many-element pattern is perceptually more salient than the individual element (as the results of Experiment 2 indicate), it is not necessarily more salient than the impression of texture (as the results of Experiment 3 indicate). Thus, "a change of

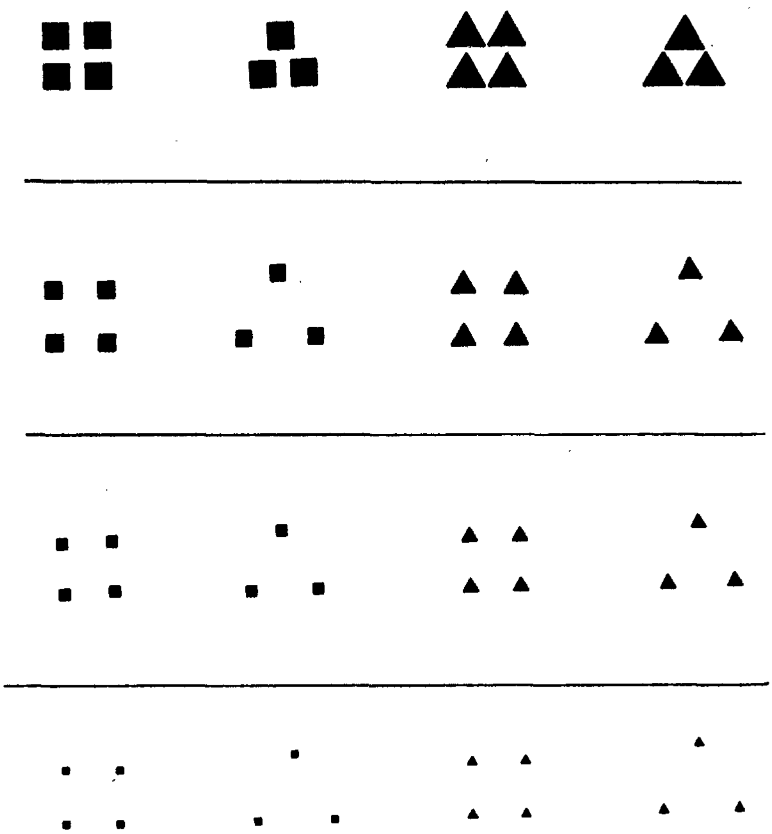

Figure 7. The set of figures from which the stimulus triads were constructed in Experiment 4.

form is by no means always more profound than a change of material" (Goldmeier, 1936/1972, p. 52). It is, however, an interesting question to ask which factors determine the relative dominance of form and texture.

Experiment 4

For the stimuli used in Experiments 1, 2, and 3, the number of elements is correlated with their size relative to the global configuration for strictly geometrical reasons: Increasing the number of elements necessarily results in decreasing their relative size as long as the spacing is kept constant. With discrete elements, however, it is possible to separate the effect of relative size from that of number by constructing patterns in which there are only a few elements that are relatively small or large. The question of interest is whether the patterns with a few small elements will produce the same results as those with a few large elements (indicating the priority of number in the perceptual organization of the pattern); those with many small elements (indicating the priority of size in the perceptual organization); or something else entirely.

Method

Subjects. Twelve new subjects, seven females and five males ages 21–32 with normal vison, participated in the experiment.

Stimuli. There were 16 stimulus triads, constructed in the same manner as in Experiment 2. The set of figures from which the stimulus triads were constructed is shown in Figure 7. The overall size of the figures (about 1.9°) and the number of elements were kept constant. There were four levels of relative size of the elements, as shown in Figure 7. Each individual element subtended .76°, .48°, .38°, and .19° in the decreasing levels of the size factor.

Procedure. The procedure was the same as in the previous experiments.

Design. The three factors of the design were size of elements (4 levels); figure (square, triangle); and subjects. All factors were combined orthogonally.

Results and Discussion

The scoring procedure was the same as in Experiment 2. The probabilities of choosing the comparison figures having the same configuration as a function of the relative size of the elements embedded in the standard figure are presented in Figure 8. A three-

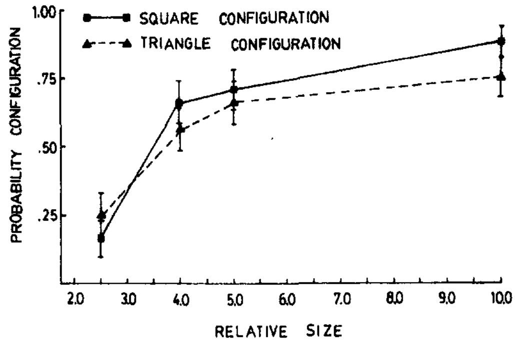

Figure 8. Results of Experiment 4: The probabilities of choosing the comparison figure having the same configuration as the standard figure, as a function of the relative size of the elements. (The relative size is represented by configuration/element ratio. The error bars represent plus and minus 1 *SE*.)

way ANOVA (Size × Configuration × Subjects) was performed. The difference between "squares" and "triangles" ($F < 1$) and the interaction between size and configuration ($F < 1$) were not significant. As expected, however, the effect of relative size of the elements was significant, $F(3, 33) = 17.72$, $p < .001$.

Further analyses using binomial tests showed that when the elements were relatively large (the first level), the probability of choosing the comparison figure having the same elements arranged in a different configuration was significantly higher than the probability of choosing the one having the same configuration composed of different elements ($p < .01$). When the relative size of the elements decreased, the probability of choosing the comparison figure having the same configuration was significantly higher ($p < .05$ for the third level in square configuration; $p < .01$ for the fourth level in both square and triangle configuration).

The present results converge with those of Experiment 2. When the relative size of the local elements decreases, the individual elements become relatively less salient than the global configuration. The form becomes phenomenally independent of its elements: Replacing the elements by different elements did not affect the perception of the global form. These results show that relative size of the element is a powerful factor in the separation between form and the material used to construct the form. Since relative size covaried with number in the previous experiments, it may have been the controlling factor there, too. Unfortunately, we cannot isolate the effect of number from the effect of relative size because the complete orthogonal design combining number and relative size would require a geometrically problematic figure—a pattern composed of many relatively large elements.

Experiment 5

The relative salience of the local elements and the global configuration of patterns was further investigated by asking subjects to choose the verbal description that best fit the patterns among four alternatives. Two descriptions used the global configuration as the grammatical subject and the local elements as the grammatical object (e.g., "A triangle made of triangles") and the other two descriptions reversed their roles (e.g., "Triangles arranged to form a triangle"). The hypothesis was that subjects would prefer descriptions in which the grammatical salience of elements and configurations in the sentence parallels their perceptual salience. When there are many small elements, the global configuration is salient; subjects should choose a description in which the configuration is the grammatical subject. When there are a few large elements, the local elements are salient; subjects should choose a description in which the elements are the grammatical subject. Thus, we expected the present results to converge with those of the previous experiments in indicating the different roles of elements in a configuration for different numbers and relative sizes of elements.

Method

Subjects. One hundred twenty-one undergraduates in a psychology course at the University of California at Berkeley participated in the experiment.

Stimuli. Twelve patterns were used. The four patterns composed of a few relatively large elements in the present experiment were the four standard figures used in Experiment 2 for the first level of number (see Figure 3, row 1); the four many-element patterns in the present experiment were the four standard figures used in Experiment 2 for the fourth level of number (see Figure 3, row 4); and the four patterns composed of a few relatively small elements were the four standard figures used in Experiment 4 for the fourth level of relative size (see Figure 7, row 4).

Each pattern was presented on a separate page, with four descriptions below each pattern. The descriptions referred to two aspects of the pattern: the global configuration and the element shape. In each description one aspect was emphasized over the other by placing the noun phrase that referred to it at the beginning of the description. Each of these two types of descriptions appeared with and without an indication of the number of elements in the pattern. For example, the four descriptions that appeared below a triangular configuration constructed from 36 triangles were (a) a triangle made of triangles, (b) a triangle made of 36 triangles, (c) triangles arranged to form a triangle, and (d) 36 triangles arranged to form a triangle. The order of presentation of the patterns as well as the order of the descriptions for each pattern were counterbalanced across subjects.

Procedure. Subjects were instructed to mark the description that best fit his or her immediate impression of the picture.

Results and Discussion

The percentages of subjects who chose each of the four alternative descriptions for each type of pattern are presented in Table 1.

The results for many-element patterns and for a few relatively large element patterns are consistent with the results of Experiments 2 and 4. Sixty-six percent of the subjects chose the descriptions that emphasized the global form as the one that best fit their impression of many-element patterns ($p < .001$). On the other hand, 70% of the subjects chose the descriptions that emphasized the local elements for few relatively large element patterns ($p < .001$).

Interestingly, the number of elements in many-element patterns seemed irrelevant to the description of the impression of the pattern, whereas with patterns of a few relatively large elements, the majority of subjects chose the description that emphasized the elements and referred to their number

Table 1
Percentages of Subjects Choosing Each of the Verbal Descriptions for Each Type of Pattern

	Pattern of elements		
Verbal description	36	3 or 4 large	3 or 4 small
Global form	60	13	8
Global form + number of elements	6	17	22
Elements	28	11	10
Elements + number of elements	6	59	60

(e.g., "Three triangles arranged to form a triangle").

Another interesting finding was that the inconsistency between the global and local level of the pattern (e.g., a triangular configuration constructed from squares) had no effect in the case of many-element patterns. This is just what would be expected if the global and local levels were perceptually separate and independent. In the case of few-relatively-large-element patterns, however, more subjects chose the description that emphasized the elements (80%) for "inconsistent" patterns than for "consistent" patterns (62%), although in both cases this description was significantly favored over the description that emphasized the global form.

The results for patterns composed of a few relatively small elements were somewhat surprising. Although similarity judgments for these patterns yielded the same results as for many-element patterns, the verbal description task yielded results similar to those for patterns containing a few relatively large elements: 70% of the subjects chose the description emphasizing the elements rather than the global form. This finding might be due to the nature of the task rather than to a perceptual effect. The perceptual salience of the global configuration in such a pattern was clearly demonstrated through the similarity judgments in Experiment 4, where the pattern was presented in the context of two comparison figures. The present task, however, involved verbal description; it seems plausible that conventions of conversation (communication) come into play. Whereas the global configuration might be easily perceived as a certain kind of form (e.g., a triangle or square), subjects may have been aware that the form was "mentally constructed," since no contours and no angles were physically present. As a result, the description that emphasized the global form might be thought of as infelicitous (i.e., misleading a listener). Thus, although the global form of a few-relatively-small-elements pattern is perceptually more salient than the individual elements (as the similarity judgments indicated), the Gricean conversational postulate charging a speaker to tell the "truth" causes the subject to choose the description that emphasizes the elements (Grice, 1975). This interpretation is supported by a pilot study for the present experiment that required subjects to generate a description that best fit the configuration: Half of the subjects referred to these patterns as having an "imaginary" form.

General Discussion

Through a set of converging operations, the present experiments have demonstrated that the perceived organization of hierarchically constructed patterns depends strongly on the number of local elements and their size relative to the global configuration. The primary theoretical questions are how to describe the phenomenological structure arising from such patterns and the perceptual processes that produce this structure.

To begin, we repeat that we use the terms *global configuration* and *local elements* to refer to logically distinct levels of geometrical structure in the stimulus domain. Whenever small figures are positioned near each other in such a way that their positions form the pattern of a larger stimulus figure, these two geometrical levels are present, regardless of the number or relative size of the elements. Whether these two levels map into two independent perceptual levels is by no means clear. Unfortunately, many researchers concerned with issues of "global" and "local" processing seem to assume that there are always parallel perceptual levels corresponding to these geometrical levels. We will argue that this is only sometimes true.

On the psychological side, there do seem to be two rather distinct perceptual entities. Goldmeier (1936/1972) called them "form" and "material," and Julesz (1975) referred to them as "shape" and "texture." But they are not to be equated with global and local levels of stimulus structure as defined above. The present results suggest that the mapping of geometrical levels from the stimulus domain into the perceptual levels of the psychological domain differs for patterns composed of many small elements and those composed of a few large elements in the following way: When many small elements comprise a configuration, the local elements are processed as texture and the global configuration as form. However, when few large elements comprise a configuration, both the local and global levels are processed as form. The difference between these two cases resides in the perceptual independence or dependence of the two geometrical levels. When local elements are processed as texture, it is hypothesized that the global configuration is perceptually independent of the local elements and coded separately from them. When the local and global levels are both processed as form, we suggest that the two are coded relative to each other.

This account attributes the "Goldmeier effect" in Experiment 1 to the relative independence/dependence of the configural and elemental levels when the number and relative size of elements varies (Goldmeier, 1936/1972). Patterns composed of few large elements are perceived to be more similar to proportional enlargements because they preserve not only the global and local structure but also the relationships between them. If both levels are coded relative to each other, it seems reasonable that an enlargement that does not distort the relationship between the two levels would produce a more similar representation than one that does distort it. The situation is different for configurations composed of many small elements, however, because the local level is represented independently of the global level. If the two are truly independent, in the sense of separate representations for form and texture, then it would be expected that an enlargement whose textural representation was identical to the standard's would be perceived as more similar to it than an enlargement whose textural representation differs with respect to size.

A perceptual theory that might account for the perceptual structure described above has recently been proposed by Julesz (1975, 1981a). Julesz has distinguished between a figure perception system and a texture perception system. Following this distinction it might be the case that the two phenomenal qualities—form and texture—reflect the involvement of these two perceptual systems. The figure perception system operates on the global configuration, whereas the texture perception system operates on the entire group of local elements. Julesz (1975) has also suggested that when the elements in a pattern are few and relatively large they resist becoming texture and are perceived by the figure perception system. Another phenomenon that supports this suggestion is the subitizing effect. A brief presentation (to avoid counting) of up to four clearly visible objects enables the observer to guess the number of objects without error, whereas with more than seven objects, performance rapidly deteriorates.

An alternative account might be given in terms of attentional mechanisms. It has been suggested that visual attention can be drawn to a small area with high resolution or spread over a wider area with some loss of detail (Eriksen & Hoffman, 1972; Treisman & Gelade, 1980). Suppose, then, that perceptual attention is drawn primarily to the entire pattern. When the pattern is composed of many and/or relatively small elements, the individual element dissolves into the overall characteristics of the design (i.e., becomes part of the texture), and the global configuration becomes the perceptual unit that draws focal attention. To process the individual elements, focal attention must be shifted to the local constituents. When the elements in the pattern are few and relatively large, they are less affected by the relatively low resolution and the way is open for different perceptual units to compete for perceptual dominance. The perceptual effect will then depend strongly on intrinsic structural properties of the pattern and its elements, and on task demands.

A fully specific theory of perceptual mechanisms underlying these phenomena must await more extensive empirical analysis. However, the results that elements are sometimes perceived as individual parts of the overall form and, at other times, as texture places constraints on perceptual processing models. For example, a model should not predict the precedence of the global level of structure as a rigid perceptual law (e.g., Navon, 1977). When the local elements serve to define texture, perhaps being perceived by a different system (e.g., the texture perception system of Julesz, 1975), the global configuration can be perceived prior to, and independently of, the local form. Indeed, the perceptual priority of the global form of a pattern composed of many relatively small elements, all else being equal, has been demonstrated in several studies (e.g. Navon, 1977; Martin, 1979; Robertson, 1981). On the other hand, when the configuration is constructed in an identical way but the elements function as individual parts of the overall form (i.e., few relatively large elements comprising the configuration), the processing of elements could even be prior to the perception of the overall form. A similar proposal has been suggested independently by Pomerantz (1981). Thus, any perceptual model will have to account for the relative perceptual separation of the configural and elemental levels when the number and the relative size of the elements varies.

The present results on the perceptual organization of hierarchical patterns suggest that researchers should be clearer in their use of terms like global and local. Since the relationship between the geometrical and perceptual levels is not always the same, the terms should not be used to refer to both domains interchangeably. Rather, a clear terminology should be developed that reflects the possibility of different sorts of mappings from geometrical to perceptual levels. We suggest that *global* and *local* be reserved for referring to levels of geometrical structure in the stimulus (similarly for *elements* and *configurations*), and that *form* (or *shape*) and *texture* (or *material*) be used to refer to perceptual levels of subjective structure. Within this kind of framework, sensible questions about the correspondence between stimuli and percepts arising from them can be posed clearly.

Reference Note

1. Lotery, J. L. *Global versus local precedence in visual perception: Questioning the role of number of elements.* Unpublished manuscript, University of California, Berkeley, 1980.

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