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Against the Likelihood Principle in Visual Form Perception

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The likelihood principle, originally formulated by Helmholtz, states that the preferred perceptual organization of a sensory pattern reflects the most likely object or event. This principle of perceptual organization is compared with the minimum principle, which has its origin in the Gestalt tradition. This principle states that we see the simplest possible interpretation of a pattern, given the constraints inherent to the perceptual system. We argue that, as far as perception of visual form is concerned, the likelihood criterion is untenable as a criterion on which the preference for one interpretation over another could be based. Our main argument is that the likelihood principle implicitly starts from interpretations of patterns, whereas it is supposed to explain the existence of those interpretations in the first place. In our view, the likelihood of an interpretation is merely one consequence of the simplicity of the interpretation.

Visual perception is a remarkably powerful process. It begins from two-dimensional retinal patterns, yet it enables one to see rigid three-dimensional objects that change position, although their corresponding projections on the retina vary greatly. One interprets these projections or proximal stimuli as a composition of single distal objects and their motion. Distal objects may even have varying shapes, but they may be classified into one category. Besides this amazing ability to pick up "invariants," perception appears to predict the world veridically. Owing to this property, people may run through woods or drive a car without tactual controls of their paths. A driver's license depends largely on one's visual ability, not on other perceptual skills. One rarely asks a witness of an accident, "Did you touch the cars?" Illusions indeed do occur, but seldom in everyday life. They are produced by scientists in impoverished laboratory conditions.

Focusing on the veridicality and predictive power of perception, one is almost forced to conclude that perception uses inferences and knowledge. On the other hand, focusing on the ability to represent the world in terms of invariants, one is inclined to think that perception aims at simplicity. According to the first option, that specific perceptual organization is chosen that corresponds to the most likely distal object. According to the second option, the simplest pattern representation will be the preferred organization.

Before we go into the question of which option is better, an antecedent issue should be considered: These two options might be two sides of one coin. Such a view is defended by Mach (1914/1959) and it indeed seems to the point if one considers some examples. In the first example we give here, inference is the most important factor (the example is taken from Rock, 1983). In the second one, the role of knowledge is crucial.

The first example is one of inference: If one suddenly hears a loud noise and, at the same time, sees a bright flash of light, this pair of stimuli can be interpreted as caused by two independent sources or as originating from one source. The latter interpretation, "it is an explosion," will be preferred. The former interpretation would accept a coincidental and unlikely state of affairs, whereas the latter does not (Rock, 1983). However, notice that the first interpretation can also be considered to be more complex than the second one. In this case, both principles may predict a preference for the same interpretation.

The second example is one of knowledge: Figure 1A is an illustration of a proximal stimulus that may lead to two interpretations: a horse with two heads, or two horses, one partly occluding the other. The first interpretation is less likely, and it is also more complex than the second interpretation. Because of an additional head and extra legs, the former interpretation can be argued to be more complex than the latter.

These examples suggest that likelihood and simplicity are merely two sides of one coin. However, we know too well that these properties are not of necessity related in this simple way, especially when knowledge is involved. For instance, a symmetrical horse can have two heads (Figure 1B) or no head (Figure 1C). Both of these horses are rather unlikely, but they do have simpler shapes than an ordinary one. Thus, we are still left with a question: Is perceptual organization determined by likelihood or simplicity? These two options, considered as principles of perception, will be developed in more detail in the next section.

Principles

Likelihood Principle

Helmholtz (1867/1962) is considered the main initiator of the likelihood principle. The principle was defined by Hochberg (1968, p. 89) as follows: "We perceive the most likely objects or events that would fit the sensory pattern that we are

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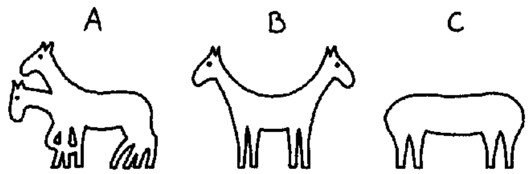

Figure 1. The horse stimuli. (In A, the simplest interpretation—two animals—also is the most likely one. In B and C, however, the simplest interpretation—a symmetrical animal—is an unlikely one.)

trying to interpret." Gregory (1973, p. 61) put it this way: "If all perceiving of objects requires some guessing, we may think of sensory stimulation as providing data for hypotheses concerning the state of the external world. The selected hypotheses, following this view, are perceptions." Pomerantz and Kubovy (1986, p. 6) defined the principle as follows: "The likelihood principle says that perception is organized to achieve the interpretation most likely to match the source of distal stimulation."

Two types of phenomena can be distinguished, both of which are explained by the likelihood principle. We will illustrate them by two examples.

1. According to the law of good continuation, a proximal stimulus made up of a linear arrangement of points will not be interpreted perceptually as an arrangement of points, but as a line segment. This phenomenon seems better explained by inference than by knowledge. An accidental linear arrangement of points can be considered as highly improbable or coincidental. According to Rock, the perceptual system tends to avoid such coincidental organizations.

2. A small proximal stimulus tends to be interpreted as farther away from the perceiver than a (congruent) large proximal stimulus, given that the small one is not enclosed by the large one. This depth effect can be ascribed to the supposedly known fact that proximal size differences are more frequently caused by differences in distance—according to the law of perspective—than by true differences in size.

The way the perceptual system actually establishes some relation between a proximal and a distal stimulus is not central to the likelihood principle. The ontogenetic version of the likelihood principle claims that perceptual organization is determined by the knowledge a person has acquired during his lifetime. The phylogenetic version holds that perceptual organization reflects knowledge which results from the phylogenetic adaptation on an evolutionary time scale. This adaptation might be due to the selection of genetic mutants.

Minimum Principle

The minimum principle states that a perceiver will see the simplest possible interpretation of a pattern, given the inherent constraints of the perceptual system. This principle is related to the law of Prägnanz, as formulated by the Gestalt psychologists (Koffka, 1935). A test of the minimum principle requires a perceptual coding system (Boselie & Leeuwenberg, 1986). The first attempt to quantify this principle was made by Hochberg and McAllister (1953). Later on, coding models, akin to Hochberg and McAlister's approach, were developed, in which this principle plays a role (Leeuwenberg, 1969; Restle, 1979; Simon, 1972).

Coding theorists are commited to the idea that an interpretation of a pattern corresponds to a *primitive code,* which is a series of symbols describing the form of an object within the language of coding theory. A primitive code can be reduced to a shorter form via a set of formal operations on the code symbols. Each code is characterized by its information load, *I*, that consists of the number of independent parameters it requires. Interpretations can be ordered according to simplicity by their information load. The minimum principle, within coding theory, is this: The perceptual system reduces *I* and under ideal conditions will arrive at the interpretation having the lowest information load (see Hatfield & Epstein, 1985 for a review of metrics of simplicity). We clarify the gist of the minimum principle by presenting some examples involving coding of simple letter patterns.

Figure 2A shows the letter sequence *aaaaa* and two different coded versions of it. One representation is the simplest version; it is *5(a)*. This code has two descriptive components or degrees of freedom: *5* and *a*. Single units of information are indicated in Figure 2 by dots below code elements. The number of dots is taken as the information load, *I*, of a code. According to the representation *5(a)*, each of the five letters is seen as a replica of one single letter. Thus, the code is characterized by the specific letter *a*, the number *5*, and in addition it is characterized by the identity structure, specifying that all letters are identical. Abstractly, this structure is shared by other patterns. Consider, for instance, the pattern *ddddd.* More generally, the pattern set *xxxxx* represents all such patterns where *x* is a parameter standing for any letter.

Next to the simple code *5(a)*, another code of the pattern *aaaaa* is shown in Figure 2A. This code, *3(a)2(a)*, has a weaker identity structure: It explicitly specifies the identity of the first three letters, *3(a)*, and also the identity of the last two letters, *2(a)*. However, note that it does not specify the relation between these two groups of letters. Abstractly, all patterns sharing this structure can be indicated by the set *xxxyy,* in which both *x* and

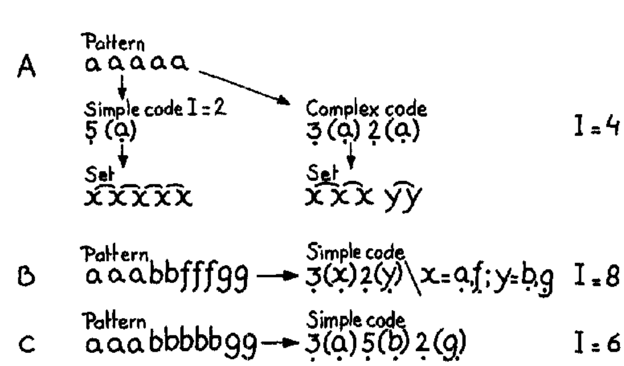

Figure 2. Some examples of codes of letter patterns. (According to the simple code of A, A is a member of the set *xxxxx,* the set of all patterns made up of five identical elements. According to a more complex code, A belongs to a less constrained set: *xxxyy.* B is coded as the repetition of a subpattern with the structure *xxxyy.* Although C can be coded by the same abstract scheme as used in the coding of B, the simplest code of C has another structure.)

y are parameters, each standing for any letter. A characteristic of this code is that it disregards the relation between the first three and the last two letters; therefore, it does not preclude that *all* letters are identical. Hence, the set induced by the first code is enclosed by the set of the second code: $xxxxx \subset xxxyy$ (Collard & Buffart, 1983). This nesting property expresses the idea that the first code is more specific and accurate than the second one.

Instead of two different interpretations of a single pattern, we can also consider two different patterns with the same identity structure. These are shown in Figures 2B and 2C. The pattern in Figure 2B is made up of two subpatterns, each with the structure *xxxyy*. This common structure is represented as $3(x)2(y)$, and can be taken as basis for the complete representation of the pattern. The representation is complete if the *x* and *y* parameters are specified as shown in the code of the pattern in Figure 2B. (Restle, 1979). Notice, however, that the description by such a common structure is not always efficient. For instance, the pattern in Figure 2C can be described in the same way as that in Figure 2B. However, it is clear from Figure 2C that another representation of this pattern is a better choice.

These examples demonstrate that the simplest pattern representation corresponds to the one which generates the greatest number of identity relations between the elements of a pattern. In addition, it is made clear that such a representation describes a pattern as a member of a whole set of patterns, all characterized by the same identity structure.

With respect to the status of the minimum principle in the theoretical analysis of visual perception, the situation is as follows. Some theorists (Attneave & Frost, 1969; Goodman, 1972; Leeuwenberg, 1969; Restle, 1979; Sober, 1975) take the minimum principle as a core explanatory principle in perception and other knowledge processes. Other investigators, however, (Hochberg, 1982; Kanizsa, 1975; Pomerantz & Kubovy, 1986; Rock, 1983) are skeptical about the role of a minimum principle in perception. One source of their skepticism derives from the fact that, in some cases, the principle merely applies to parts of a pattern, instead of to the pattern as a whole (see next section). This *local effect phenomenon* has been demonstrated by Hochberg (1982) and Kanizsa (1975).

With respect to the likelihood principle, the ontogenetic version of this principle finds no favor by students of perception, whereas there are many theorists who adhere to the phylogenetic version (Brunswick, 1956; Gregory, 1974; Helmholtz, 1962; Perkins, 1976; Pomerantz & Kubovy, 1986; Rock, 1983). Of course, they interpret the principle in many different ways and accept it in different degrees. In the following section we will comment on one reason why theorists are drawn to the likelihood principle. Specifically, we consider why a preferred perceptual organization may seem very likely. Next we will discuss the role of knowledge in perception. Although no serious student of perception will defend the ontogenetic likelihood principle, we will nonetheless pay some attention to it, because the alleged role of knowledge in perception can be most clearly discussed in that context.

Inference-Based Likelihood

If one happens to meet two persons with identical faces, one is surprised and would consider such a resemblance to be a highly unprobable coincidence. This unlikely coincidence undoubtedly stimulates one to look for a "common cause" which produces the resemblance: "Aha! They are twins!"

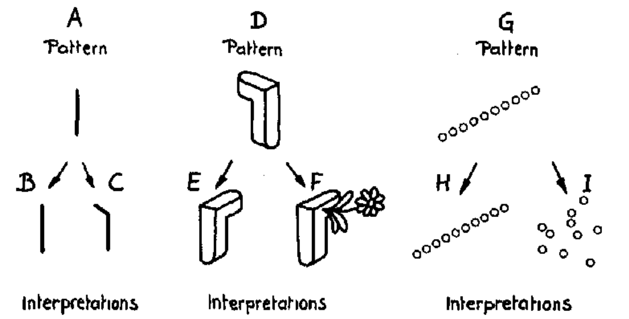

Figure 3. A can be interpreted as a stick (B) or as a hook (C). (A is a more probable projection of B than of C under all their transpositions and rotations in three-dimensional space. E and F show possible backsides of D. D can be interpreted as a hook [E] or as a hook with a flower [F]. Although D is an equally improbable projection of both E and F, D preferentially will be interpreted as illustrated by E. This preference can be explained by simpicity. G preferentially is interpreted as a linear arrangement of balls [H], and not as a random arrangement [I]. It demonstrates that it is almost unavoidable to interpret patterns.)

As already indicated, the tendency to avoid coincidences and to explain them by inferring some common cause, is, according to Rock (1983), a core characteristic of perception. For instance, a proximal line pattern, such as in Figure 3A, will not be interpreted as a special side view of a hook (e.g., Figure 3C) but rather as a stick (Figure 3B). Imagine the hook rotating about an axis congruent with its vertical leg. There should be noticeable differences in its orientation as it turns through 360°. Note, however, that with respect to the perspective of an observer, only *two* of these orientations will produce retinal line projections. These occur when the upper leg points exactly toward or away from the eye of the beholder. None of the other orientations does produce a line projection. However, if a stick is turned, *all* of its projections produce a line pattern! Hence, given a proximal line pattern, a stick interpretation is more likely than a hook interpretation.

Although this likelihood explanation may seem rather attractive, we doubt whether the alternative ways in which a certain object may be imagined by a perceiver play a decisive role in choosing a perceptual organization in general. Two options about these alternatives will be distinguished. Option 1 is congenial to the likelihood principle. It has been used in discussing the preferred interpretation of the line pattern of Figure 3A. In that example, the different projections of an object, resulting from rotating and transposing the object in three spatial dimensions, were considered. Option 2 links up with the minimum principle. It is slightly different in that it supposes that the set of alternative objects is related to the representation of a pattern. That is, the descriptive components within a representation are supposed to induce the set to which the object belongs. We introduced this idea when discussing the minimum principle (see Figure 2A). Here we will apply it to the stick and hook interpretation of the line pattern of Figure 3A. The stick interpretation includes a three-dimensional orientation and a length specification. The set to which the stick belongs, according to this representation, can be indicated by *wx*. The symbol *w* stands for any orientation and *x* for any length. We assume that the size of this set equals the product of the number of noticeable orientations and the number of noticeable lengths. The hook representation contains, in addition to a three-dimensional orientation and a line length, an angle and another line length. The induced set we indicate by *wxyz*. Now notice that, because the stick interpretation can be considered as a borderline case of the hook interpretation, the set induced by the stick interpretation is nested in the larger set induced by the hook interpretation. This follows from our previous discussion of nesting pattern representations. Thus, according to its description, a stick belongs to a smaller set than a hook, and because of this the stick-interpretation can be considered the more likely one. It appears thus that Option 2 favors the same interpretation as Option 1. In what respect do these options differ?

The idea of induced sets originates from Garner (1970). However, Garner was concerned with sets induced by external transformations of an object (e.g., rotations; Option 1), and not *with sets induced by the descriptive components of a representation* (Option 2; Collard & Buffart, 1983). It can be easily demonstrated that Option 1 is less generally applicable than Option 2. In Figure 3D a hook pattern is presented in which one leg is longer than the other one. Two possible interpretations of this pattern are visualized in Figure 3E and 3F, both showing the inferred backside of the pattern in Figure 3D. Any perceiver will see that the pattern in 3D is more likely completed as indicated by Figure 3E and not as shown by Figure 3F. Why does the average perceiver not imagine a flower on the opposite side of Figure 3D (e.g., as in 3F)?

According to the likelihood reasoning of Option 1, Figures 3E and 3F made visible by rotation and transposition, are considered as alternative interpretations of Figure 3D. All projections of Figure 3F are, under these transformations, different. However, this is also true for the projections of Figure 3E. Therefore, the size of the set induced by the interpretation of Figure 3E equals the size of the set induced by the interpretation of Figure 3F. Figure 3D is a member of both sets. Hence, there is no reason to consider 3E a more likely interpretation of Figure 3D than 3F is. In short, Option 1 does not tell us why the perceiver does not imagine a hidden flower.

This conclusion is rather counterintuitive. One expects Figure 3F to show some part of its protruding flower in many of its projections as it turns. It is simply improbable that Figure 3D is one of the views of 3F. However, in estimating probability in this way, notice that one is actually taking 3E and 3F themselves *once more* as patterns! But they are not patterns. They are interpretations of a given pattern, Figure 3D. The sets induced by 3E and 3F were proposed, following Option 1, as explanations of a preferred interpretation. Therefore, they cannot become second-order interpretations, after the fact.

Contrary to Option 1, Option 2, based on the minimum principle, does explain the preference for the interpretation of Figure 3E. Because Figure 3E is simpler than 3F, the set induced by 3E is smaller than that induced by 3F. Because an object taken from a small set has a higher probability of occurence than an object taken from a large set, Figure 3D is a more probable view of Figure 3E than of 3F. An additional advantage of Option 2 is that it links preferred interpretations to the representations of objects. Representations are essential to perception. Without representations recognition would be impossible.

We are now in a position to sharpen the formulation of Option 2. Option 2 implies that set size is based on simplicity, not the other way around. Because likelihood is derived from set size and the latter from simplicity, we can do without likelihood and without set size as criteria of perceptual preference. In this context, they are completely redundant and secondary concepts.

Although we consider the likelihood aspect of an interpretation merely as a derivative of the simplicity of an interpretation, we do not deny its strong appeal when perceiving the world. The likelihood of what one perceives seems so strong because one is not aware of the perceptual process that transforms a proximal stimulus into a perceived object. It is almost impossible not to interpret proximal stimulation. In Figure 3G, for instance, one sees a number of balls in a line without feeling the slightest inclination to see this pattern as a random configuration. If it is interpreted as a random configuration, as in Figure 3I, then its *representation would contain a great number of descriptive elements* and the size of the induced set of configurations, therefore, would also be very large. Because of the size of this set, 3G would be an unlikely configuration. If, on the other hand, Figure 3G is seen as a regular arrangement of balls, as in Figure 3H, all of which have the same relative position, then its representation requires only a few descriptive terms, and the induced set of configurations consequently will be small. As a consequence, Figure 3G will be a rather probable configuration. Note that the same tendency to prefer simple interpretations inclines one to see the subpatterns of Figure 3G as balls. One does not feel inclined at all to see these subpatterns as, for instance, concatenations of pieces of curved line segments!

In summary, people take an interpretation for a piece of reality. Once an interpretation is taken for a piece of reality, its likelihood is a self-evident property. That is why the likelihood principle so easily dominates one's thinking about perception. In our opinion, however, the likelihood aspect is just a secondary implication of the perceptual interpretation process, which runs its course without one being aware of it.

Knowledge-Based Organization

Ontogenetic Likelihood Principle

According to the ontogenetic likelihood principle, knowledge acquired during a lifetime plays a role in perception. However, many studies have demonstrated that knowledge and context hardly affect perception (Rock, 1983). One of the first demonstrations was given by Gottschaldt (1950). He presented the same pattern a great number of times to subjects. Subsequently, he presented another pattern in which the first one was embedded. He found that subjects did not recognize the first pattern in the second one, except when the second pattern was ambiguous. He concluded that in the process of perceptual organization of a pattern, the Gestalt laws overrule the familiarity of subpatterns. Figure 4 presents two examples that demonstrate this lack of context effect in pattern perception. The whole pattern 4A, the left part of which (the hexagon) is the context of

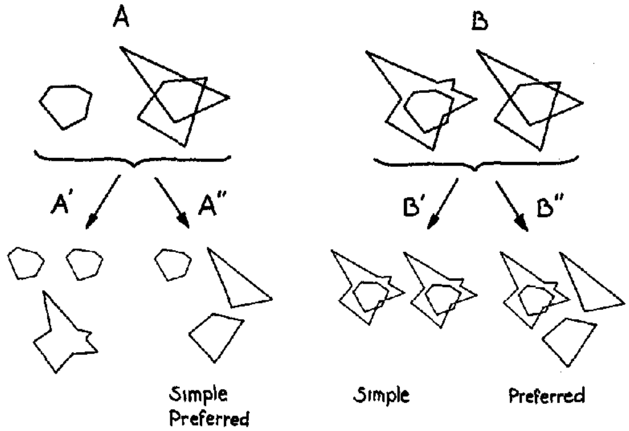

Figure 4. Two demonstrations of the lack of effect of context on perceptual organization, restricting the likelihood principle. (In interpretation A', the right part of A is organized as a combination of forms, one of which is the hexagon on the left side of A. In interpretation A", the left and right side of A are organized independently. A" is simpler than A'. A preferentially is interpreted as illustrated by A". In interpretation B', there is an effect of the left part of B on the way the right part is organized. In B", the left and right part of B are organized independently. B' is simpler than B". B preferentially is interpreted as illustrated by B". B demonstrates a restriction of the minimum principle.)

the right part, might be organized as visualized in Figure 4A'. However, preferentially it is organized as illustrated in Figure 4A". That is to say, a context-independent interpretation of the part at the right is preferred. This context-free interpretation of 4A as a whole turns out to be the simplest interpretation of this pattern. In this example, thus, familiarity of a subpattern is overruled by simplicity.

There is a second restriction on context effects. This relates to the local effect phenomenon. In some cases, a simple description of part of a pattern, one which is *incompatible* with a simple description of the pattern as a whole, overrules the simplest description for the whole pattern (i.e., the globally simplest). This local effect was discovered after the minimum principle had been formulated, and it constrains it (Boselie, 1988; Hochberg, 1982; Kanizsa, 1975). An example is given in Figure 4B. Pattern 4B might be organized as visualized in Figure 4B', but preferentially it is organized as illustrated by Figure 4B". That is to say, in this case too, a context-independent interpretation of the right part of the pattern is preferred, although this time, this interpretation is not the simplest one, globally.

Both examples given in Figure 4 restrict the ontogenetic likelihood principle. They demonstrate that perceptual organization does not strongly depend on knowledge. Moreover, leaving aside these examples, there are other arguments to suggest that at least some aspects of perceptual organization must be knowledge independent. Of necessity, there must be a phase in the development of a perceiver in which the preference for one interpretation above another cannot be determined by probabilities based on experiencing the world, namely, at the very start of life. The only way out is to assume that preferences at least originally are based on some other factor rather than that of experience. This argument has been made by Köhler (1940) and more recently by Rock (1983). But even leaving aside this primary stage of perception, there are additional reasons to assume that perception without organization principles is not feasible. Without such principles, perception then would merely be a process of registering unstructured proximal stimuli. This implies that every stimulus instance must be compared as a template with all other stored templates. Each template would possess unique properties, and perceptual classification would hardly be possible. It is no wonder that template-matching models, and related approaches such as structuralistic and empiristic views of perception, have been severely critized (Hochberg, 1982; Koffka, 1935; Neisser, 1967).

The local effect phenomenon, demonstrated in Figure 4B, shows that a global minimum principle is constrainted by locally minimal descriptions. As a matter of fact, a minimum principle of necessity has to be limited to some local stimulus. Hochberg (1982) therefore rightly draws attention to the problem of defining how big a stimulus is. If local effects did not exist, the perceptual system had to postpone the organization of incoming information till it dies, because each forthcoming input in principle can lead to a better organization of all input received till then. This would imply that stimuli never get organized at all.

Now let us consider cases where context and knowledge do seem to have an effect on perception. There are in fact also many examples of context-dependent interpretations. One example is the interpretation given to the letter pattern *mmmm* in Figures 5A, 5B, and 5C. This pattern is shown in three different contextual situations: 5A, without context; 5B, in the context of a symmetrical pattern; and 5C, in the context of a repeated symmetrical pattern. Figures 5A', 5B', and 5C' present a series of context variations analogous to those of Figures 5A, 5B, and 5C. Here we will focus on the letter patterns of Figures 5A, 5B, and 5C. The pattern in Figure 5A can be described in two ways: as a repetition or as a symmetry. The repetition interpretation contains less descriptive elements than does the alternative symmetry interpretation; therefore, it will be preferred. Notice, however, that if the pattern in 5A is presented in the context of

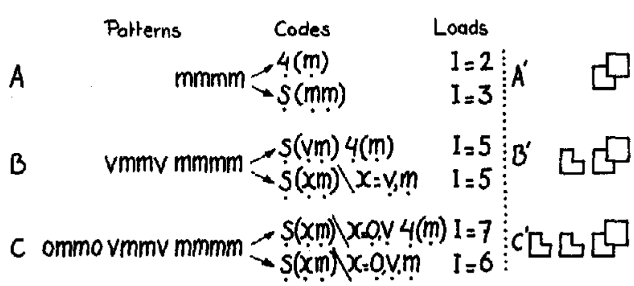

Figure 5. A demonstration of interacting frequencies. (The letter pattern *mmmm* is shown in three different contextual situations: A, without context; B, in the context of a symmetrical pattern; and C, in the context of a repeated symmetrical pattern. The minimum information loads *I* of the different interpretations of patterns A, B, and C predict that, as the weight of the symmetrical context increases from A to C, the tendency to interpret the pattern *mmmm* as symmetrical will increase also. Patterns A', B', and C' also show a similar increasing effect of context.)

a symmetrical letter pattern as in Figure 5B (*vmmv*), the repetition interpretation of the *mmmm* pattern contains the same number of descriptive elements as the symmetry interpretation and the pattern therefore will be perceptually rather ambiguous. But with an additional repetition of the symmetry context, as in Figure 5C (*ommo*), the whole context eventually does change the way the *mmmm* pattern might be perceived. Now the symmetry interpretation is simpler and, therefore, more attractive than the repetition interpretation.

In fact, Figure 5 shows the interaction of two types of frequencies: the repetition of the single *m* element on the one hand, and the repetition of the symmetry structure on the other hand. Figure 5 is designed to clarify that no part of a pattern has a privileged status as a chunk beforehand. According to our point of view, a pattern is not made up of parts which are "given" in advance. Parts are constituted from general perceptual principles; they are not stumbled upon. The decision to take a particular part of a pattern as a chunk might be determined by the interpretation of a pattern as a whole. Figure 5 demonstrates that the choice of a chunk is based on its relative frequency. This conception of the choice of chunks is at variance with the more common idea, which takes a particular "thing" as an uncontested basic unit and which takes the frequency of this thing as a supporting property, instead of founding the choice of this chunk in its frequency. Frequency is usually conceived of as an obvious property of real things. However, frequency is merely a specific kind of regularity of an interpretation of a pattern. In fact, the line of thought proceeding from these examples leads us to doubt the role of unconscious inferences, because inferences take some parts of a pattern as a self-evident point of departure for the interpretation of the whole pattern.

Only in ambiguous situations is one potentially aware of the choice of a particular perceptual category. But once a choice has been made, the conceptualization stage fades away. For instance, if one sees red grass, there is a moment of uncertainty. It is an ambiguous situation. One wonders whether one is seeing grass or perhaps some unknown plant. Thus, frequency, or more generally, regularity plays a crucial role in the construction of our concepts. It is obvious, therefore, that the concepts one actually uses are more frequently relevant than other ones. In other words, their likelihood is an implication of the conceptualization process. But this process, in turn, is always guided by principles of regularity and simplicity.

Phylogenetic Likelihood Principle

Several specifications of the phylogenetic likelihood principle can be considered. First, Perkins (1976) has conceptualized that "the minimum is the best bet." Second, the Gestalt laws of perceptual organization can be taken as bets or biases, that are programmed into our nervous system by natural selection. This is the position defended by Pomerantz and Kubovy (1986), who tended to support the likelihood principle. This position implies that the phylogenetic likelihood principle offers the best explanation of perception. We contend that it does not. This is largely because the phylogenetic likelihood principle is not falsifiable. It states that reality has selected some bias or principle, whether the principle involves complexity (e.g., "complexity is the best bet") or rigidity (e.g., "rigidity is the best bet") or another organizational scheme. But this means that the likelihood principle can always be considered to be right! As an explanatory principle, that makes it comforting, of course, but also meaningless. The real point for a psychological theory is found, finally, not in such appeals to evolutionary process, but in what is selected by the process. In this respect, we suggest that, as selected principles, Gestalt laws are more meaningful than others, in part, because they do permit falsifiable predictions about perception.

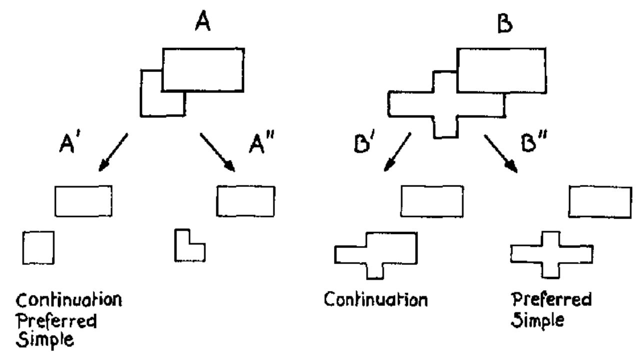

Figure 6. Any Gestalt law can be overruled by other ones. (Interpretation A' of pattern A obeys to the law of good continuation, interpretation A" does not. Interpretation A' is the preferred one. Although interpretation B' of pattern B also obeys to the law of good continuation, whereas B" does not, B", nonetheless is the preferred interpretation of pattern B. In both cases, A and B, predictions based on simplicity prove to be correct.)

Pomerantz and Kubovy (1986) have evaluated most of the important Gestalt laws. They compared the likelihood and simplicity of the preferred perceptual organization as described by each of these laws. Their tentative conclusion is that the perceptual organization hypothesized by these laws is more often likely than simple. We grant their conclusion. However, we consider such comparisons of likelihood and simplicity a hazardous enterprise when quantifiability of both constructs is not possible. As we have seen, it is indeed possible to quantify simplicity (e.g., via coding models), but an equally rigorous metric is not available for the likelihood principle.

As Pomerantz and Kubovy (1986) were, we too are inclined to believe that each simple Gestalt law predicts the perceptual organization of all kinds of patterns rather well, on the condition that no other law is involved. The most commonplace situations, however, usually demand application of more than one Gestalt law. Here problems arise. Traditional Gestalt laws, when taken together, have considerable difficulty predicting perception in these circumstances. This is because there is no priority rule stipulating which laws overrule other ones. The lack of such a priority rule is due to the interdependency of these laws: They share common features. Their interrelations are therefore murky. The Gestalt laws have been formulated to specify the perceptual organization of patterns, but their own organization is lacking. Any Gestalt law can be falsified by another one or by some others. Figure 6 gives an example. The pattern in Figure 6A tends to be organized as shown in Figure 6A', and 6B tends to be interpreted as shown in 6B". The perceptual organization of 6A, thus, obeys the law of good continuation, whereas the organization of 6B produces a counterexample of this law. Why is this?

Let us compare the Gestalt qualities of the two alternative organizations of Figure 6B: B′, continuation and convexity; B″, bilateral symmetry and similarity.

Starting from these qualities, we really cannot decide which organization should be the preferred one. Furthermore, if one scrutinizes the qualities, it becomes evident that most of them are at least partly implied by other ones. They all are varieties of similarity. However, similarity (i.e., identity) is basic to the minimum principle. This will be clear if one considers the complexity of the interpretations of Figures 6A and 6B: 6A′ is judged as more simple than 6A″, and 6B″ as more simple than 6B′.

In this context it is important to note that there seem to be two types of organization rules. One type includes laws such as similarity, good continuation, common fate, and symmetry. These laws are akin to the minimum principle. The other type of organization rules includes constancies such as depth cues, area (an enclosed area usually is closer to a perceiver than its surrounding), proximity, and direction of light (light usually comes from above). These rules represent a specific property of the world we live in. However, it makes more sense to take the Gestalt laws and the constancies together and to make a distinction that offers a unifying perspective. This distinction introduces two components: a formal aspect and a content aspect. This applies to both organizational relations and to constancies.

Formal aspect. The identity structure of an interpretation is a formal aspect. Relations of identity are common to all things in the world. In coding models, identity relations are described by conventional operators like repetition, symmetry, and so on. The minimum principle merely has a bearing on the formal structure of a representation. There is an intricate relation between the formal identity relations (repetition, symmetry, etc.) and their arguments: They are mutually dependent. The choice of both the type of identity relation and of its argument (the *chunk*) are guided by the minimum principle. In this selection process alternative operators as well as alternative arguments are compared.

Content aspect. All kinds of content can be arguments for a particular formal structure. Abstractly, content can be described as an argument, for instance, k. In the identity structure $3(k)$, the argument k can apply to either elements in organized patterns or to ones in constancies: k can be a pattern element such as an angle, a complex pattern code, or even a piece of knowledge.

Notice that only regular patterns can be represented in a simple way, and that random patterns can not. Our conclusion is that when frequencies, regularities and similarities (i.e., simplicity) would not be noticed, the perceived world would be chaos.

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