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Good Patterns Have Few Alternatives

Information theory's concept of redundancy helps in understanding the gestalt concept of goodness

Over half a century has passed since a school of psychology was founded and named for the German word *Gestalt*, a word which has been carried over into English because there is no translation of it which seems quite to carry all the connotations of the German word itself. In general terms, a gestalt is a form, a figure, a configuration, or a pattern. But gestalt is also the quality that forms, figures, and patterns have. Thus gestalt is both form and form-ness, pattern and pattern-ness. The school of psychology was given this name because of its emphasis on studying the form and pattern characteristics of stimuli, rather than on studying the elements which make a stimulus but which do not in and of themselves constitute the pattern.

Since patterns (the word we will use for the gestalt) can have pattern-ness, we can talk about good patterns as those patterns which have a lot of pattern-ness, and poor patterns as those which have little pattern-ness. It is not always clear just what we do mean by saying a pattern or figure is good or has goodness, but we certainly can agree that circles are good patterns, squares almost as good, stars somewhat less good, and that ink blots are rather poor patterns. This problem of what makes some patterns good and others less good was a topic of very active research for many years, but the research seemed to produce as many explanations of pattern goodness as there were patterns to have the goodness or to be good. There seemed to be no explanatory principles which were very general in application.

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The concept of redundancy

Then, after World War II, along came information theory. Introduced by Claude Shannon and Norbert Wiener, this theory dealt, not with physical properties of signals (stimuli, to the psychologist), but with their informational properties. This concern with the nonphysical properties of stimuli struck a familiar note to psychologists concerned with problems of patterns, gestalts, and similar things, because after all wasn't that the essence of the distinction the gestalt psychologists had been trying to make years earlier?

In addition, information theory provided the very special concept of *redundancy*, a concept not unlike its ordinary lay meaning, but defined more formally and capable of quantification. Redundancy is surplus information, and it is evidenced by regularities in signal systems. For example, because *u* regularly follows *q* in English, the *u* provides very little information over and above that provided by the *q*. Here indeed was a measurable concept which might help provide some understanding of why some gestalts are better than others, why some patterns seem to be good patterns and others to be poor patterns. The good patterns are the redundant patterns, because the whole is so highly predictable from any part, while the poor patterns, being unpredictable, are not redundant.

There is indeed a relation between the information theory concept of redundancy and pattern goodness, but this relation is not as direct as it might be. First, we have to consider that a stimulus is a member of a set of meaningfully related stimuli, and for any set we can form various meaningful subsets. Second, the relation between redundancy and goodness must be understood in terms of the size of the subsets that can be formed and redundancy, because redundancy as a *quantitative* concept is directly related to the size of subsets, not to the individual stimulus itself (Garner 1962, 1966). In order to see how redundancy affects pattern goodness, we must first examine the relation between redundancy and size of a subset of stimuli, and then show that the size of the subset of stimuli is related to pattern goodness. To anticipate ourselves, the relation we will see is that small subsets are more redundant than large subsets, and stimulus patterns in small subsets are better patterns than those in large subsets.

Total sets of stimuli

First we must realize that any stimulus can be defined in terms of attributes or variables which have different levels. Patterns or figures or stimuli can be large or small, dark or light, blue or red. The larger the number of attributes, and the greater the number

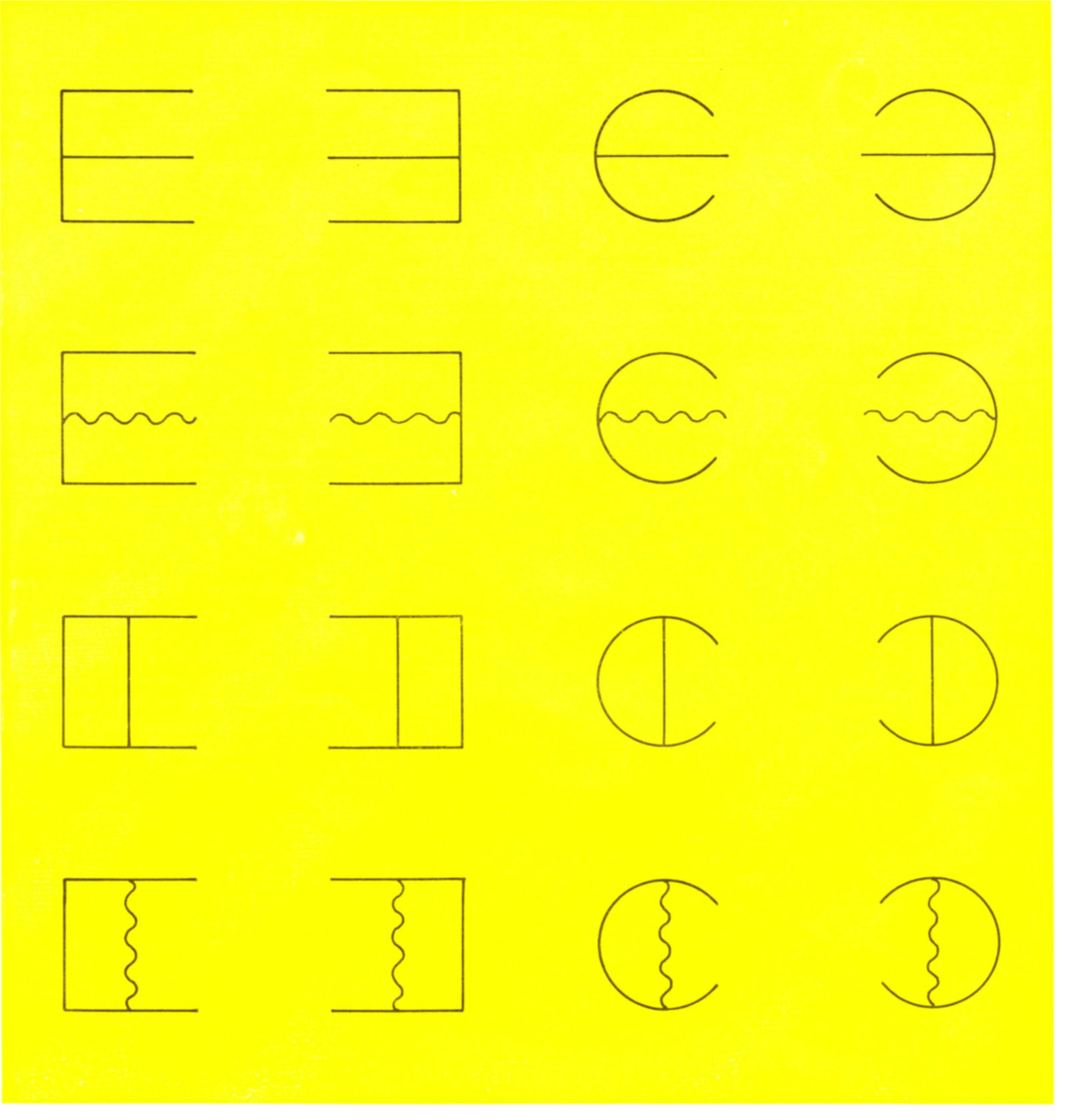

Fig. 1. A total set of patterns. These 16 patterns are all that can be formed from the four dichotomous attributes of (circle or square) $\times$ (open on the right or left) $\times$ (vertical or horizontal line) $\times$ (wavy or straight line).

of different values of each attribute, the more stimuli there are that could have been generated, or that can be seen as meaningful alternatives to the particular stimulus in question.

Figure 1 contains, for purposes of illustration, a particular total set of stimuli. In this case we have stimuli which differ in respect to four attributes, each attribute having two levels or values. These stimuli are either circular or rectangular, so form is one attribute. Position of the opening, left or right, is another attribute; position of a center line, horizontal or vertical, is a third attribute; and the center line can be either straight or wavy, giving us the fourth attribute. Now with four two-leveled attributes, 16 and only 16 stimuli can be formed, this value being the product of the number of levels of each attribute: $2 \times 2 \times 2 \times 2 = 16$. This set of 16 stimuli constitutes a total set because it contains all the stimuli which can be generated with these particular attributes and levels.

Redundant subsets

Now we want to see what happens when a subset of these 16 stimuli is selected. The principle is that the selection of any subset is simultaneously the process of producing redundancy; or, alternatively, any subset from a total set is redundant or contains redundancy.

Consider the trivial case where we select eight stimuli, all of them being squares. Clearly the attribute of form has become redundant since it no longer differentiates among these eight stimuli. But that is not an interesting case, and we could even argue that all we have done is create a smaller total set. Now consider the eight stimuli in Figure 2. In this subset of stimuli all attributes are represented, and furthermore, each level of each attribute occurs exactly half the time. What has happened? A little inspection will show that the square is always open on the right, and the circle is open on the left. Thus the two attributes of form and position of the opening are completely correlated, and clearly one or the other of them can be considered redundant. We could, in describing these eight stimuli, neglect either form or position of the opening, and we would still have eight different patterns. So selection of a subset has created redundancy.

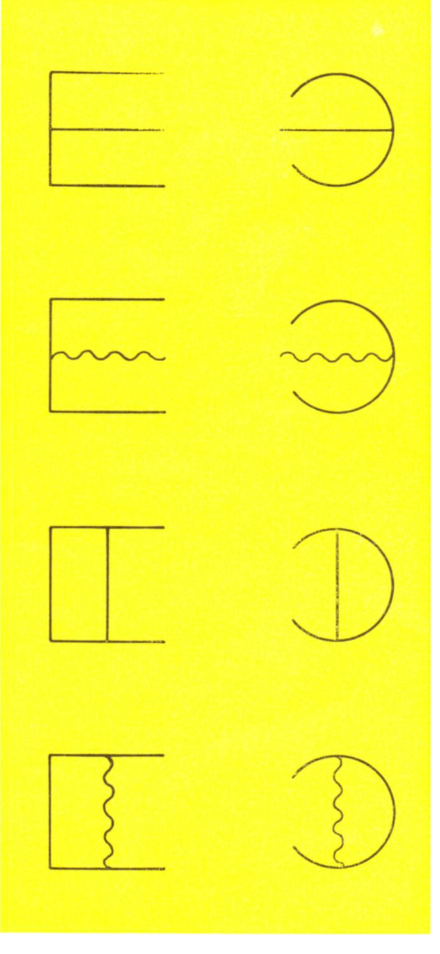

Fig. 2. A redundant subset of eight patterns. Any subset of patterns is necessarily redundant. In this subset the redundancy is due to the perfect correlation of square with right side open and circle with left side open. Thus if there were no differences in form, or alternatively no differences in position of opening, there would still be eight different patterns. So one or the other of these attributes can be considered redundant.

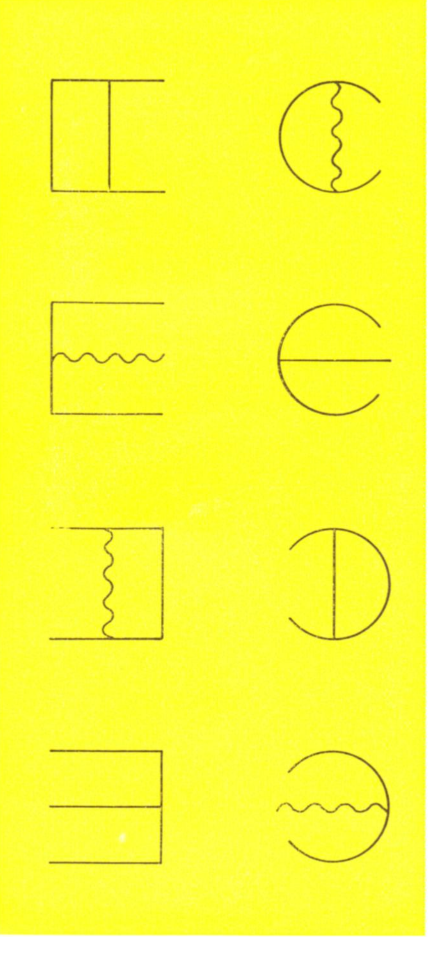

Fig. 3. Another redundant subset of eight patterns. In this subset the redundancy is harder to see because there is no simple correlation between any two attributes. But any one of the four attributes can be eliminated and the remaining three attributes will still provide eight different patterns. For example, if all the wavy lines are made straight, there will still be eight different patterns.

A more complicated subset of eight stimuli is shown in Figure 3. Here again all attributes are represented, and each level of each attribute occurs exactly four times. But inspection this time will reveal that no pair of attributes is perfectly correlated. This particular subset has a more complicated form of redundancy, but its existence can easily be seen by noting that even if we remove any one attribute in describing these eight stimuli, the eight stimuli will still all be different. The fact that any one attribute can be eliminated makes it more difficult to see the redundancy, but in both this subset and the previous one, exactly one attribute can be eliminated without making the stimuli the same, so we have the same amount of redundancy.

One further illustration will show that still smaller subsets have even more redundancy. In Figure 4 we have a subset of just four figures, and once more all attributes are represented and each level of each attribute occurs exactly twice. In this subset, however, there are two pairs of correlated attributes: The open end is always on the right of the square and on the left

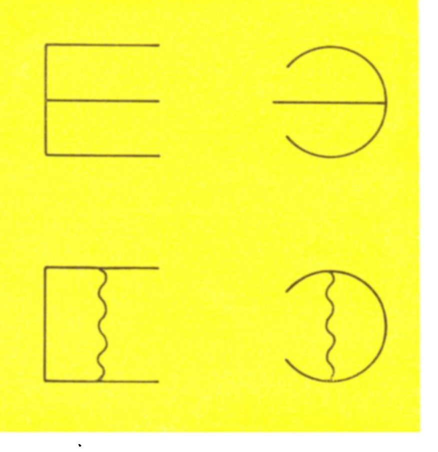

Fig. 4. A smaller subset of four patterns. The smaller the subset, the greater the amount of redundancy. With this subset we can eliminate both the square-circle attribute and the line orientation attribute and still have four different patterns. Since only two attributes are necessary to produce four patterns, two of the attributes are redundant.

of the circle; and the vertical line is always wavy while the horizontal line is straight. Thus we could eliminate either the form or open position attribute, and either the direction or nature of the center line, and there would still be four different stimuli.

With subsets of eight stimuli we can eliminate one attribute and still have eight different stimuli. With subsets of four stimuli, we can eliminate two attributes and still have four different stimuli. So the selection of a subset from a total set produces redundancy; the smaller the subset, the greater the amount of redundancy, because the smaller the subset, the more attributes that can be eliminated.

Dot patterns

This is all very well, but how do we relate the redundancy of subsets of stimuli such as these to the kinds of stimuli which have what we would ordinarily call pattern, gestalt, or configuration? Furthermore, we do not really want to talk about the goodness of subsets at all, but of individual stimuli. How do we relate the redundancy of subsets to the goodness of particular patterns? The answer lies in seeing that a particular pattern can be considered as representing a subset of stimuli, or in some way having equivalent stimuli which, together with the pattern we are interested in, form a subset. If such subsets of equivalent patterns contain different numbers of stimuli, and if size of subset relates to pattern goodness, then we will be able to see the relation between the goodness of an individual pattern and the redundancy of subsets of patterns.

To show this relation experimentally (Garner and Clement 1963), we have used patterns of dots, such as those shown in Figures 5–9. These dot patterns were created by placing exactly five dots in the imaginary cells of a matrix with three rows and three columns. Although there are 126 different possible patterns of dots, we used only 90 of them, avoiding patterns which have no dots in a particular row or column, because we felt that such cases might be a bit confusing.

The first thing we did with these 90 dot patterns was to ask a group of people to rate each of them for pattern goodness on a seven-point scale. This turned out to be quite an easy task for people to do. They rated some patterns as very good, others as very poor, and many as intermediate. And different people agreed with each other very well as to which patterns are good and which are poor. Thus we have little doubt about the goodness of the patterns themselves, as evidenced by the unanimity among the evaluators.

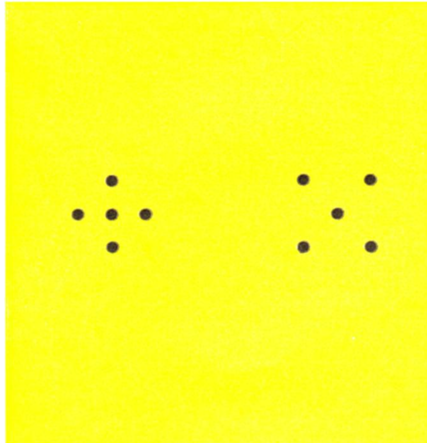

Fig. 5. Each of these patterns is unique, since any 90° rotation or any reflection produces the same pattern again. These patterns are rated as very good.

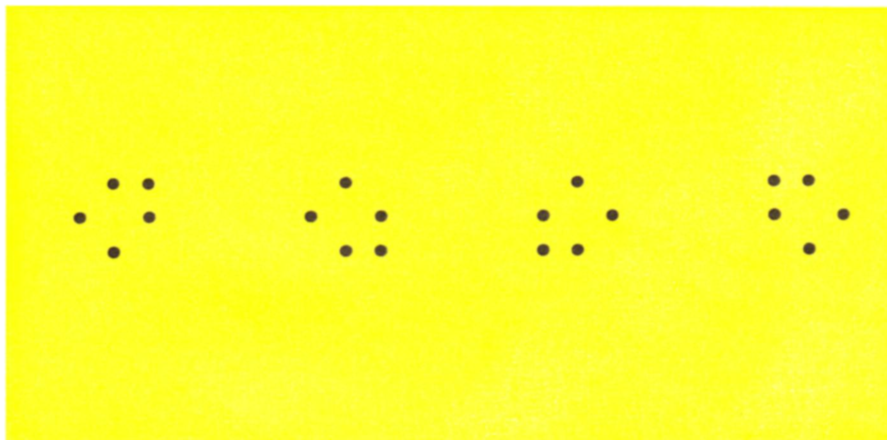

Fig. 6. Each of these patterns will produce the others when rotated in 90° steps and/or reflected. These four patterns thus form a single R & R subset.

Rotations and Reflections

But then what about putting the patterns into different subsets? What rules should be used for deciding which patterns should go together? With patterns formed from an original square matrix a fairly obvious set of rules to use is to rotate the pattern by 90° steps and also to mirror or reflect it around the horizontal, vertical, or either diagonal axis. By carrying out these rotations and reflections, we can put all 90 patterns into groups—subsets—of either one, four, or eight different patterns, giving us three different subset sizes.

Only two of the patterns form groups of one when rotated and/or reflected: These are the + and × shown in Figure 5. With either of these patterns, it doesn't matter how many rotations you use, or whether you reflect it, or rotate and reflect it, the pattern always produces itself again. Thus each of these patterns is unique with respect to the rotation and reflection criteria. It hardly needs to be said that these unique patterns are rated as "good" by practically everybody.

The way in which patterns are rotated and reflected to produce other patterns is illustrated in Figure 6. The pattern on the left is rotated in successive 90° steps to produce the other three patterns; obviously then any of these four patterns can produce any of the others by rotation. These patterns can be considered as reflections of each other just as well. The second pattern is a vertical reflection of the first, and the pattern on the extreme right is a horizontal reflection of the pattern on the left. Likewise, the third pattern from the left is a horizontal reflection of the second pattern, and a vertical reflection of the fourth pattern. Still further, the first and third patterns are reflections of each other about the left diagonal axis, while the second and fourth patterns are reflections about the right diagonal axis. Thus we can see that the rotation and reflection criteria are very intimately related and must be used together with patterns like these.

A subset of four such patterns, which we will call an R & R (rotation and reflection) subset, can be represented by any one of the four patterns in it, since the other three patterns can be produced from just that one. Altogether, there are eight R & R subsets which have exactly four patterns in them, and a representative pattern from each of these subsets is shown in Figure 7. The rated goodness of the 32 patterns which form these eight R & R subsets is intermediate.

A subset of eight patterns which form a single R & R subset is shown in Figure 8. Each of the top four patterns produces any of the other three by simple rotation in 90° steps. Likewise, any of the bottom four patterns can produce any of the other three by rotation in 90° steps. In addition, patterns on the two lines can produce each other by various reflections or combinations of reflections and rotations. As the patterns are actually arranged, each pattern on the bottom row is the horizontal reflection of the pattern immediately above it. In addition, however, the top left pattern is the vertical reflection of the third pattern from the left on the bottom, and each pattern on the top row has a vertical reflection on the bottom row. The top left pattern is a reflection of the second pattern on the bottom about the left diagonal axis, and each pattern on the top has both a right and left diagonal reflection on the bottom. So once again we see that the rotation and reflection criteria are intimately related.

There are seven R & R subsets of eight patterns each, and one representative pattern from each of these seven subsets is shown in Figure 9. Altogether,

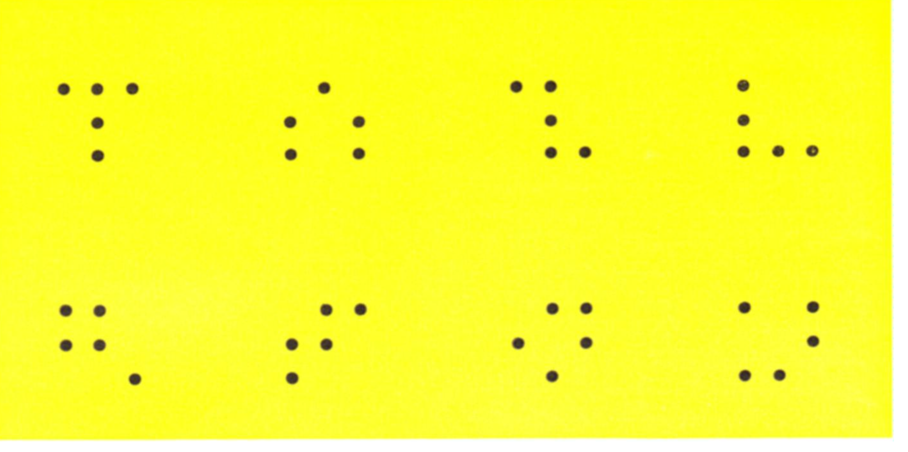

Fig. 7. Each of these patterns can produce three equivalent patterns by rotation and/or reflection. The rated goodness of these patterns is intermediate.

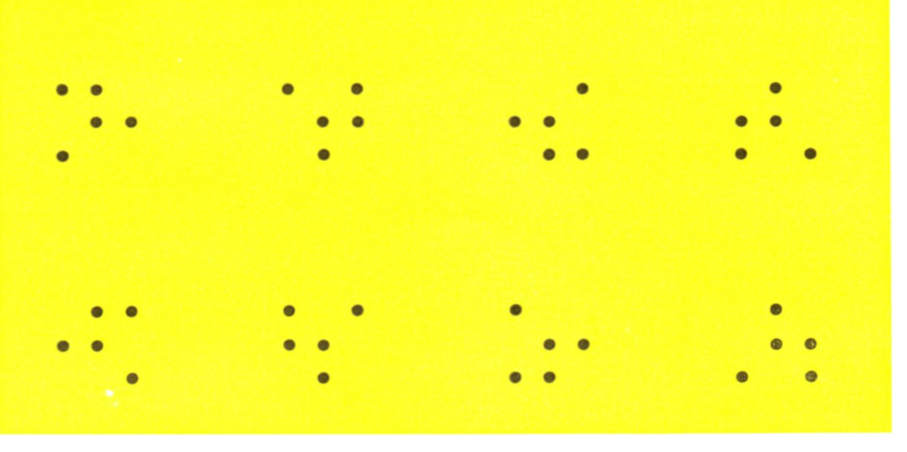

Fig. 8. Each of these patterns will produce the others when rotated and/or reflected. These eight patterns thus form a single R & R subset.

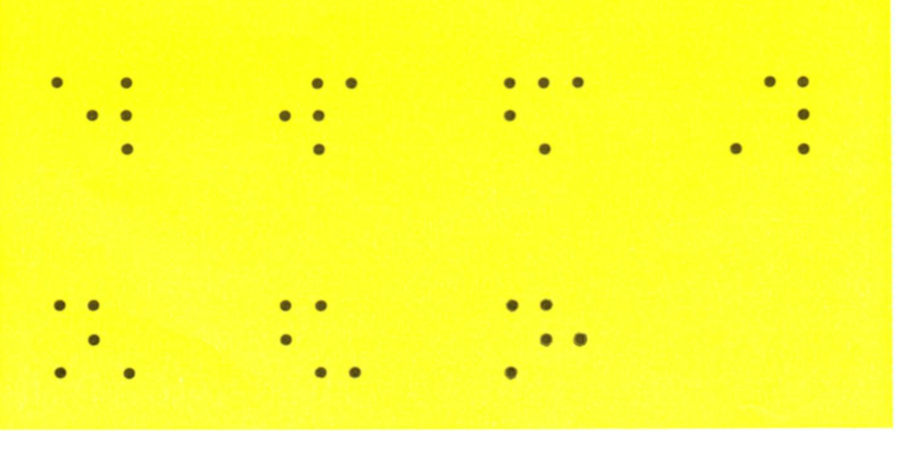

Fig. 9. Each of these patterns has seven patterns which are equivalent by rotation and/or reflection. Their rated goodness is poor.

then, 56 patterns come from R & R subsets with eight patterns in them. The rated goodness of these patterns was very poor.

Our expectation that good patterns would come from small subsets and poor patterns from large subsets has been realized, at least for these relatively simple patterns. And because of the inverse relation between subset size and redundancy, we can feel that good patterns are in some sense redundant, although the nature of the redundancy may not always be as easy to see as in the patterns used here.

In these patterns, we can think of the redundancy as being due to the duplication of pattern that occurs when the pattern is rotated or reflected. Thus the two unique patterns are most redundant because any rotation or reflection produces exactly the same patterns. The R & R subsets of four patterns are still partly redundant, because some of the rotations produce the same patterns as some of the reflections, so that only three different patterns can be produced with rotation and/or reflection of any one of these patterns. On the other hand, the R & R subsets of eight patterns are least redundant because each pattern can produce seven others by rotation and reflection.

Symmetry

Redundancy is related to subset size in an even more direct and intuitively obvious fashion, in that the number of different patterns formed by rotation and/or reflection is fairly directly related to the amount of symmetry in the patterns. In fact, the reflection criterion is exactly what we mean by symmetry since, if a pattern is reflected and produces itself, we say that the pattern is symmetrical. And we can talk about amount of symmetry in terms of the numbers of axes about which symmetry exists for a given pattern. To illustrate, note that the two unique patterns in Figure 5 are symmetrical about all four axes: the vertical, horizontal, right diagonal, and left diagonal. Thus these patterns are maximally symmetrical.

Most of the patterns in Figure 7 are symmetrical about a single axis. The axis of symmetry is obvious when it is vertical or horizontal, as it is in the two patterns on the top left. All of the patterns on the bottom, plus the L pattern on the top right, are symmetrical about a diagonal axis, and this axis is sometimes hard to find. For example, in the second pattern from the left on the bottom, the obvious axis of the pattern is the right diagonal, but symmetry does not occur about this axis. It does occur about the other diagonal axis, but this axis of symmetry is at right angles to the axis of the pattern itself.

All the patterns in Figure 9, those in R & R subsets of eight, have no axis of symmetry at all. Thus these illustrations give us the general principle that the more axes of symmetry a pattern has, the better the pattern is.

If symmetry is directly related to pattern goodness, why don't we just say that symmetry is the pertinent factor, rather than subset size and its related concept of redundancy? The answer is partially given by the third pattern on the top in Figure 7 (the Z): although this pattern is not symmetrical about any axis, still it is from an R & R subset of four members, and its judged goodness is the same as the other patterns of that subset size. So we see that symmetry is a usual concomitant of small subset sizes and redundancy, but not a necessary one. The important relation is that poor patterns have many alternatives, good patterns have few alternatives, and the very best patterns are unique.

Associations to patterns

There are some interesting secondary consequences of this relation between pattern goodness and the number of alternatives a pattern has. If one of the properties of a pattern is that it has few or many alternatives, then we might expect that various ways of describing or labeling a pattern will reflect this relationship, and it turns out that they do (Clement 1964). We can ask people to describe these patterns, and then note how many different descriptions we get from a large number of people. When we do this, we find that relatively few different descriptions or verbal associations are given to good patterns, but almost as many verbal associations as there are people are given for the poor patterns.

A still further consequence of these relations is found when we measure how long it takes people to produce the verbal associations; it takes considerably longer for the poor patterns than for the good ones. It has been known for some time that reaction times are longer when there are more possible responses for a person to give, so this result is a natural consequence of the fact that the poor patterns produce more different verbal associations than good patterns.

Words are not the only means of making associations to patterns, and in fact we can use patterns themselves as associations to other patterns. When we use this technique (Handel and Garner 1966), we get some additional understanding of the relation between subset size and pattern goodness. The number of patterns used as associations to a given pattern is much greater for the poor patterns than for good patterns—much greater, that is, than we would expect just from knowing the differences in R & R subset size. This result comes about because almost any pattern—good patterns as well as poor patterns—will be used as an association to a poor pattern, but only good patterns will be used as associations to other good patterns.

This relationship means that there is a directionality to the pattern association process, and a simple illustration of this is shown in Figure 10. The

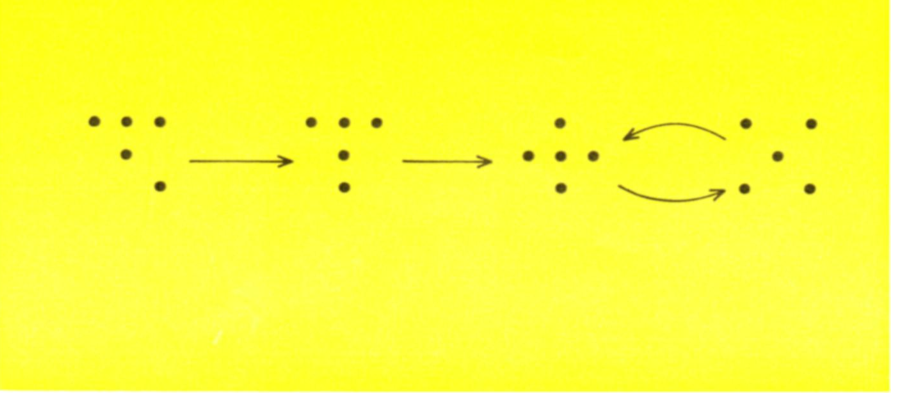

Fig. 10. An example of unidirectional effects when patterns are produced as associations to other patterns. The patterns on the left will progressively produce those to the right. The two unique patterns on the right will produce each other as associations, but will not produce those to the left.

arrows indicate the direction in which associations are made. The pattern on the left, which comes from an R & R subset of eight patterns, produces as an association the T pattern, which comes from an R & R subset of four patterns, but the reverse relation does not hold. In turn, the T produces an even better pattern as an association, the +. The + produces the ×, and the × in turn produces the +, so here we have a symmetrical association relation, but only with the very best patterns.

The general asymmetry of associations means that the process of association will always, sooner or later, produce very good patterns, regardless of how good or how poor the patterns are to start with. Somehow the human organism develops its perceptions toward good patterns and away from poor patterns.

Patterns in time

So far we have been talking entirely about visual patterns in space. But it is just as possible to have patterns in time as in space, and with temporal patterns it seems natural to use the auditory sense, just as with spatial patterns it seems natural to use the visual sense. Temporal patterns, like spatial ones, clearly can be good and poor also, in the sense, again, of having more or less "pattern-ness." Can we show that good temporal patterns have few alternatives in a way that is at least analogous to what we have found for spatial patterns?

To begin, we had to find a way of producing temporal patterns that would allow us to know exactly how many patterns there are (the total set), and also how this total set of patterns can be formed into meaningful subsets. Our solution was to generate patterns that were eight elements long, in which each element could have only two possible values. In musical terms, we are going to have melodies formed from just two notes, and the melodies will be eight notes long, although they will continue indefinitely after starting. In our actual experiments with temporal patterns, we did use the auditory sense, but our two notes were not very musical. Rather, they were two different-sounding doorbell buzzers, played at the comfortable marching rate of two "notes" per second.

Altogether there are 256 different sequences of eight dichotomous elements that can be formed ($2^8 = 256$). A few of these sequences are rather meaningless for our problem, however, because they could have been formed from shorter sequence lengths than eight. To illustrate, let us use × and O to represent the two possible notes, as we have done in Figures 11–14. One actual sequence of eight elements is ××××××××, and another is OOOOOOOO, but since there is no variation of the note, there is no real pattern in these sequences.

Another actual pattern is ×O×O-×O×O, but this one could have been formed from sequences two elements long; when this pattern is repeated indefinitely there is no way to tell that it was actually generated from sequences eight elements long. Still another pattern is ×××O×××O, but this one could have been generated from sequences four elements long rather than eight, as could the sequence ××OO××OO.

Basic patterns

But even after eliminating the sequences that could have come from a shorter length than eight (which are as a consequence very simple and easy), we have a large number left that could only have come from a sequence of length eight. These remaining sequences can be grouped into meaningful subsets by taking note of the fact that once a sequence is started it continues indefinitely without a break, and if somebody begins to listen to the sequence sometime after it has started, he cannot know how the sequence started.

In this sense, eight different actual patterns are all the same basic pattern, as is illustrated in Figure 11. The top pattern is ××O××O×O, but the other seven patterns are all exactly the same as this one except for being displaced in time. Certainly an observer cannot tell one pattern from another unless he knows at what point in the sequence the pattern started.

We shall refer to this subset of eight sequences as a basic pattern, and when we talk about a specific pattern, we need only specify the basic pattern and

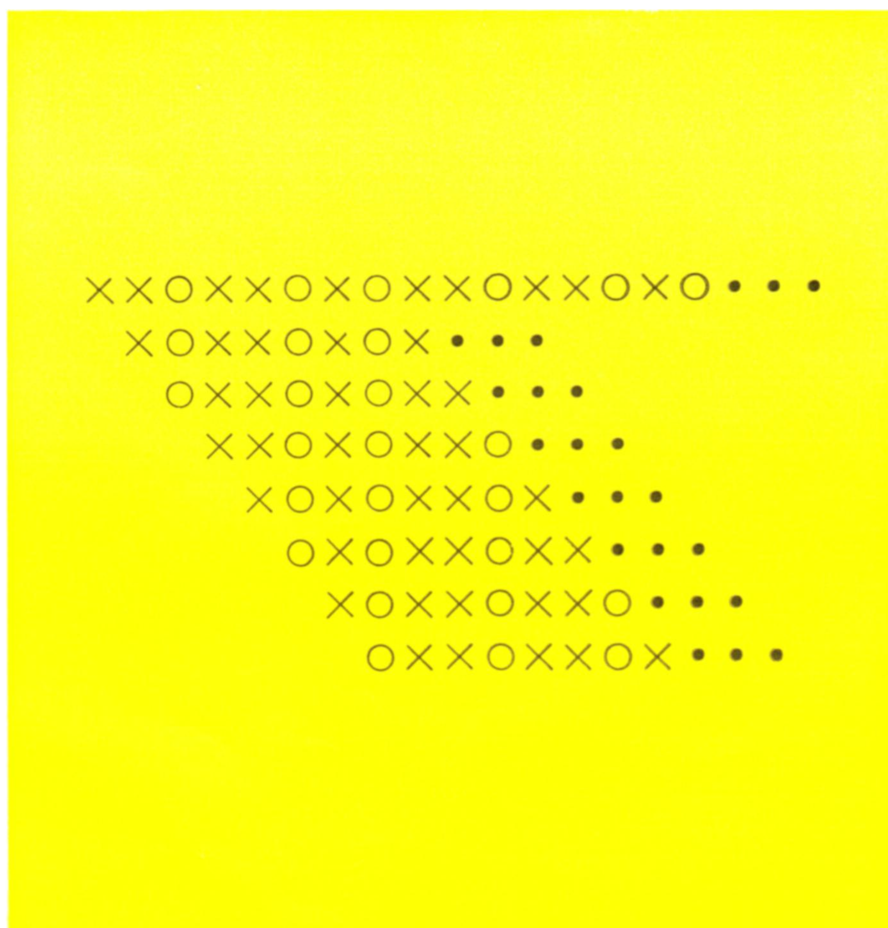

Fig. 11. The top pattern consists of eight sequential elements repeated indefinitely and without pause. The other seven patterns, also of eight elements, are identical to the first pattern except for starting at a different point in the continued sequence. All eight patterns form one basic pattern, and each specific pattern must be defined in terms of its starting point.

its starting point. The 16 different basic patterns that are eight elements long are shown in Figures 12–14.

Accent points

It seemed so obvious to us that these patterns differed in goodness that we did not ask people to rate them, but instead directly investigated some relations between difficulty of pattern perception and number of alternatives. It should be noted that each of these basic patterns actually has eight alternative starting points, so in this objective sense each of these basic patterns is the same subset size, therefore has the same redundancy and should be equally good. But it is equally obvious that the number of *subjective* starting points for these different basic patterns is not the same at all. The good patterns have few meaningful starting points, but the poor patterns have many starting points, although none of them is more meaningful than any other.

This subjective starting point we call an accent point because it is exactly like the musical accent point. As one of these patterns is played continuously, the pattern becomes organized into a subjective pattern, a gestalt, in which there is a very definite beginning and end. A particular pattern can have more than one accent point, and with an effort the listener can change the accent point while listening to the continuing sequence.

However, it takes a little time for these patterns to appear organized so that they have definite beginnings and ends, and until this subjective organization is perceived it is essentially impossible to "play" the pattern by tapping it out on two keys. Yet once the sequence is heard as a pattern, it is very easy to play it on the two keys.

In our experiments on these patterns we had people listen to the continuing sequence until it became an organized pattern, at which time they either began to play the pattern in synchrony (Royer and Garner 1966) or they simply stopped the pattern and described it (Garner and Gottwald 1968). Either of these methods easily establishes how the pattern is heard, because either the beginning of the description or the beginning of the playing defines an acceptable accent point. (We used all possible starting points in presenting the sequences so that the accent points obtained would not be biased by our selection of starting points.)

Pattern difficulty

These experimental procedures gave us two measures concerning the perception of these temporal patterns. One measure tells us how many acceptable accent points there are, as well as what they are; the other tells us how difficult it is to perceive the sequence as an organized pattern. Insofar as difficulty of pattern is related to goodness (inversely, of course), the smaller the number of acceptable accent points, the shorter the time it should take for the sequence to become a subjectively organized pattern. And that is exactly what happens.

These 16 different basic patterns are easily grouped into three sets according to the number of acceptable accent points each has. Seven of them have just two acceptable accent points, and they are shown in Figure 12. These patterns include all those with just two "runs" (sequences of the same note) in them, plus three with a moderately long run and some alternations. The importance of the run can be seen by noting that the two acceptable accent points occur at the beginning of the longest run, or on the note immediately after the longest run. The locations of these two acceptable accent points mean that the sequence is perceptually organized so that the longest run occurs either at the beginning or at the end of the pattern. The average number of notes heard before people began to play these patterns was 22, or fewer than three complete cycles.

Another seven basic patterns have three acceptable accent points, as shown in Figure 13. These patterns are clearly more complex, or less "good" than the patterns in Figure 12, and this fact is reflected in the greater number of acceptable accent points. Once again the longest run determines two of the accent points, one at the beginning of the run and the other at the first note after it, but the factors determining the location of the third accent point are more complex. The average number of notes heard before people began to play these patterns was 34, or more than four complete cycles. Thus the increased number of accent points is accompanied by increased perceptual difficulty.

Fig. 12. These seven temporal patterns have two acceptable accent points, as underlined. People can play these patterns in synchrony before they hear three complete cycles.

Fig. 13. These seven temporal patterns have three acceptable accent points, as underlined. People can play these patterns only after hearing more than four complete cycles.

Fig. 14. These two temporal patterns have six acceptable accent points, as underlined. People need to hear more than six complete cycles of the top pattern, and twelve complete cycles of the bottom pattern before they can play them in synchrony.

Two of the basic patterns have six acceptable accent points, as shown in Figure 14. Both patterns have just two runs of two notes, and the only notes in the sequences not acceptable as accent points are the second notes of these runs. These are quite complex patterns, and a long time is required for people to perceive them as organized patterns. The bottom pattern took an average of 104 notes before it could be played. This pattern is unique in that the second half of the pattern is the same as the first half except that the notes are reversed, and this relation is true for any possible accent point. The pattern is much like some of the reversing figures used in visual research, and there is no way of invoking an accent point which avoids the reversal.

Perhaps now we can understand why circles and squares are good patterns, whereas ink blots are not; there are very few ways in which circles and squares can be made, but many ways in which ink blots can be made. This smaller number of ways circles and squares can be made is the same thing as redundancy, and thus there is a direct relation between pattern goodness and redundancy. To summarize, poor patterns are those which are not redundant and thus have many alternatives, good patterns are those which are redundant and thus have few alternatives, and the very best patterns are those which are unique, having no perceptual alternatives.

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