

Reinterpreting Visual Patterns in Mental Imagery

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In a recent paper, Chambers and Reisberg (1985) showed that people cannot reverse classical ambiguous figures in imagery (such as the Necker cube, duck/rabbit, or Schroeder staircase). In three experiments, we refute one kind of explanation for this difficulty: that visual images do not contain information about the geometry of a shape necessary for reinterpreting it or that people cannot apply shape classification procedures to the information in imagery. We show, that given suitable conditions, people can assign novel interpretations to ambiguous images which have been constructed out of parts or mentally transformed. For example, when asked to imagine the letter "D" on its side, affixed to the top of the letter "J", subjects spontaneously report "seeing" an umbrella. We also show that these reinterpretations are not the result of guessing strategies, and that they speak directly to the issue of whether or not mental images of ambiguous figures can be reconstructed. Finally, we show that arguments from the philosophy literature on the relation between images and descriptions are not relevant to the issue of whether images can be reinterpreted, and we suggest possible explanations for why classical ambiguous figures do not spontaneously reverse in imagery.

At least since Berkeley's time, the question of whether mental images can be ambiguous has held a central place in the debate over the nature of imagery. It is easy to see why the two issues are so closely related. The process of perception begins with the geometry of the retinal images, and ends with a description of objects in the world. The controversy over imagery has largely concerned whether images are like early perceptual representations containing information about the geometric properties of visual inputs, or like later

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cognitive representations containing information about the conceptual categories of interpreted objects (Kosslyn & Pomerantz, 1977; Pylyshyn, 1973). If memory images preserve some of the geometric information in perceptual representations, it should be possible for the imager to recognize the presence of an object category in an image that was not originally assigned when the object was first seen. In the most dramatic case, an imager should be able to observe an ambiguous figure, such as a Necker cube or a duck/rabbit, see it as one object (e.g., a duck), form a visual image of it when it is no longer present, and then be able to see it as the other object (e.g., a rabbit). On the other hand, if memory images are records of the conceptual category or interpretation assigned to the stimulus when it was viewed, and information about its geometric properties is lost or not readily accessible to interpretative processes, then a reassignment of the category of an object should be impossible; the imager should be stuck with whatever interpretation he or she assigned to the stimulus when it was visible.

Several experimental investigations have cast doubt on people's ability to recategorize images of ambiguous figures. An experiment reported by Reed (1974) explored whether subjects could detect "hidden" figures in images of patterns that were composed of combinations of geometric forms. For example, one of the patterns was formed by superimposing two equilateral triangles, one pointing up, and the other pointing down, positioned such that the vertex of one was centered on the base of the other. After a brief retention interval, the subjects were shown a second pattern, and their task was to say whether or not that pattern was a part of the first pattern. Reed found that subjects could easily detect only those parts that would enter into a structural description of the pattern, such as one of the equilateral triangles, but not a part that cuts across the elements of such a description, such as a parallelogram. Reed and Johnson (1975) later found that the parts not fitting into the original composition of a complex pattern could be detected much more easily when subjects could inspect the original patterns at the time of testing, than when they had to rely on a memory image. Because subjects in these experiments could rarely detect the hidden parts in their images, these results suggested that images, unlike visually perceived forms, cannot be reinterpreted or reorganized. Rather, what is detected in an image may depend entirely on how the imagined pattern was initially conceived (see also the relevant work of Hinton, 1979, and Stevens & Coupe, 1978).

These findings conflict with the observations of other imagery theorists who have claimed that the ability to "see" new patterns in an image is one of the prime functions of imagery, for example, in scientific and artistic creativity (Shepard, 1978). More importantly, there are demonstrations that people *can* detect new patterns in transformed images. Pinker and Finke (1980) reported a series of experiments in which subjects were able to "see" shapes that emerged in the projection of a three-dimensional configuration

of objects after it was mentally rotated. Shepard and Feng (reported in Shepard & Cooper, 1982) demonstrated that subjects could quickly name the letter resulting from a transformation (rotation, reflection, or some combination of the two) of a starting letter. For example, when given the transformation "rotate 90 degrees" and the starting letter "N," subjects could reconstrue the resulting image as a "Z." In an experiment similar to those of Reed, Slee (1980, Experiment 3) found that subjects were able to judge, with success rates greater than chance, whether various geometric forms were present as embedded figures in patterns they had imagined. In another experiment, Slee demonstrated that subjects could construct a mental image from separately viewed pieces and then detect emergent forms resulting from a reorganization of the imagined pieces according to the Gestalt laws of proximity and common fate. Hollins (1985) had a group of subjects imagine a grid and mentally fill in certain squares specified in terms of their Cartesian coordinates. On different trials, the experimenter dictated patterns of filled-in squares resembling a dog, a pitcher, a wall plug, a car, and a telephone. Subjects were able to say what the resulting image depicted on about half of the trials.

Related indirect evidence comes from experiments on visual synthesis of parts. Palmer (1977) had subjects mentally synthesize patterns by mentally superimposing two visually presented parts consisting of connected line segments. They then had to match the synthesized pattern against visual probes. The task was easiest when the subpatterns corresponded to perceptually "good" geometric figures such as triangles and boxes, as opposed to open or disconnected collections of line segments. However, subjects reported that even when the original subpatterns were not "good," they "looked" for emergent "good" figures in the synthesized whole, with greater or lesser success on different trials. Apparently, at least some subjects were quite successful with this strategy: Their matching times were uniformly fast for shapes synthesized out of good, moderately good, and bad parts. Thompson and Klatzky (1978) obtained this effect more uniformly by having subjects mentally superimpose sets of visually presented angles and lines that together defined unified geometric shapes such as a parallelogram. They found that subjects really did treat the result as an emergent single form: When matching these patterns against probe stimuli, they were no slower when they had synthesized the pattern by superimposing two or three parts than when they had actually seen the pattern in its entirety.

However, a paper has appeared recently whose authors try to make a strong case that the reconstruction of mental images is impossible. Chambers and Reisberg (1985) conducted a set of four experiments aimed at assessing whether people can reinterpret an ambiguous figure stored in a mental image. In their experiments, subjects inspected ambiguous forms, such as the "duck/rabbit" figure commonly used to demonstrate multistability in visual perception (e.g., Attneave, 1971), and were then instructed to form

mental images of the forms and to try to see the reversals in their images. Although the subjects were previously trained in detecting such reversals using other types of reversible figures, they never once reported the correct reversal in their imagery. This negative finding persisted even when the subjects were screened for high imagery vividness. In addition, the subjects *were* able to reverse the figures when they later drew the figures from memory and inspected their drawings. Chambers and Reisberg concluded that mental images are therefore not subject to reconstrual, in contrast to visually perceived forms, because images do not contain uninterpreted information; the implication is that images are *nothing but* interpretations or construals. Chambers and Reisberg also offer reasons why the earlier demonstrations of emergent pattern recognition in images should not be considered as bona fide examples of reconstruing an image. They attempt to draw further support for their claims from arguments in the philosophical literature on imagery, which putatively show that images must consist of or at least be accompanied by interpretations, rather than being raw percept-like entities.

The issue of whether images can be reconstrued is of crucial importance to the study of imagery and mental representation. If reconstrual is possible, then images are not *just* conceptual or symbolic representations, but must also contain some of the geometric information available to interpretive processes in perception. In this article we examine the general claim, made most recently by Chambers and Reisberg, that people cannot reconstrue images, and the explanation for such a deficit that would claim that images lack "uninterpreted" information pertaining to the geometry of an object, or that such information is sealed off from the procedures that derive conceptual interpretations from visual geometric information. We show that, on the contrary, given suitable conditions people can reconstrue, reinterpret, or assign a novel conceptual description to a pattern represented in an image. Furthermore, we argue that (a) there are no sound arguments why such abilities should not be considered as examples of reconstrual; (b) there are alternative explanations of why duck/rabbit figures, Necker cubes, and the like would be difficult to reverse in an image even if people do possess the ability to reconstrue imagined patterns in general; and (c) arguments in the philosophical literature on imagery, such as those cited by Chambers and Reisberg, have no relevance to this strictly empirical question.

To begin with, we report three demonstrations of experiments in which subjects are presented with descriptions of a pattern, and are then asked to report new patterns that are embedded in the described figure, or are asked to identify the name of a new object that the described pattern depicts. These new objects were unlikely to have been predicted from the initial description, since the initial description implied a construal of the pattern very different from the one we expected subjects to be able to make.

Such a demonstration is necessary because the previous literature on seeing emergent patterns in images does not provide evidence on image recon-

strual that is sufficiently strong to convince a skeptic. Chambers and Reisberg point out that in most cases of apparent image reconstrual, subjects could have generated images of candidate reconstruals and compared each candidate against the original images, until a match was found. For example, in the Shepard and Feng study, subjects could have imagined each letter of the alphabet to compare it with a rotated "N," stopping when they generated a "Z," and noted its structural identity with the rotated "N." Chambers and Reisberg argue that hypothesizing an interpretation and then verifying it against an image is not the same as spontaneously assigning a novel interpretation to the image based on its inherent geometric properties. Although we will argue later that such a distinction is not a useful one, it would still be useful to show that subjects can report a novel appropriate construal of an imagined pattern in cases where a pattern must first be construed according to one description, and then another construal is detected which has a vanishingly small chance of being hypothesized a priori.

There are other weaknesses in the previous findings of image reconstrual that motivate the present studies as well: First, it is possible that the reconstrual of the imagined stimulus was noticed during the perceptual encoding of the stimulus, and was not actually detected for the first time in the image. Second, the reconstrual rates are so low that one might view the occasional reconstrual of an image as the exception rather than the rule. Accordingly, we will present the results of new studies in which the task is simple enough to elicit high reconstrual rates (if subjects do indeed possess such a capacity), in which the new interpretation of a pattern could not have been the result of some subjects having encoded that interpretation while the stimulus was actually visible, and in which the subjects are not asked to verify *whether* a form is present in an image, but must *discover which* form is actually present.

EXPERIMENT 1

In this experiment, we asked subjects to superimpose or juxtapose mental images of familiar patterns, such as alphanumeric characters and simple geometric forms, to see if they could mentally detect any new patterns as a result of their combination. In particular, we were interested to see whether subjects could "reparse" the features in one imagined form when the other was combined with it, enabling them to recognize patterns that were not present in either form separately.

Our task differs from those of Reed (1974) and Slee (1980) in one important respect: Instead of requiring that a single imagined form be reorganized or reconstrued in order to detect certain features, in our task the features to be detected would not be available until two imagined forms were combined in the proper way. For example, subjects would be asked to imagine an upper case "X" superimposed upon an upper case "H," which should result in

the depiction of a butterfly, a bow-tie, the letter "M," four right triangles, or other recognizable forms. Thus, subjects would be given the information necessary to create an ambiguous image (e.g., a form that could be construed either as a "superimposed H and X" or as a "butterfly"), and would be tested for their ability to assign an alternative construal to the image and report it.

Method

Subjects. Twelve undergraduate students at the State University of New York at Stony Brook served as subjects, in partial fulfillment of a research requirement in an introductory psychology course.

Procedure. The subjects were tested individually in one-hour sessions. They were told that the experiment would investigate certain characteristics of mental imagery, and that they would be asked to visualize patterns formed out of combinations of familiar symbols or shapes. The experimenter would then ask them to describe any new features or patterns that they could detect while inspecting their mental images. Because the experimenter would be in contact with the subjects throughout the experiment, we were careful to use a naive experimenter in this and all following experiments, as recommended by Intons-Peterson (1983).

The experiment began by showing the subjects two demonstrations of what we wanted them to try to do using their imagery. For example, they were first told that they might be asked to "imagine a square," and were shown a drawing of a black outlined square on a white background, to illustrate exactly how their initial mental image should look. This was followed by the instruction "Now add a diagonal line connecting the upper right-hand corner and the lower left-hand corner," and by the presentation of a second drawing in which the line was added to the square in the described manner. This second drawing depicted how the subject's image should look after the second pattern was added to it. The experimenter then pointed out on this drawing examples of emergent forms that could be detected, such as two right triangles having a common hypotenuse, the letter "Z," and an upside-down "N."

The subjects were told that in the actual imagery task they were to report as many of these emergent forms as they were able to detect. In every case, they were to line up the described patterns in their images so that end points or edges would always match up. Letters were always to be imagined as capital letters. When reporting the emergent patterns, they were to be as precise as possible about the relative size, orientation or position of the patterns. If they didn't know the name of a particular form or shape, they were to describe it in their own words.

Following the demonstrations, the experimenter instructed the subject to close his or her eyes, and then read descriptions of one of six pairs of experi-

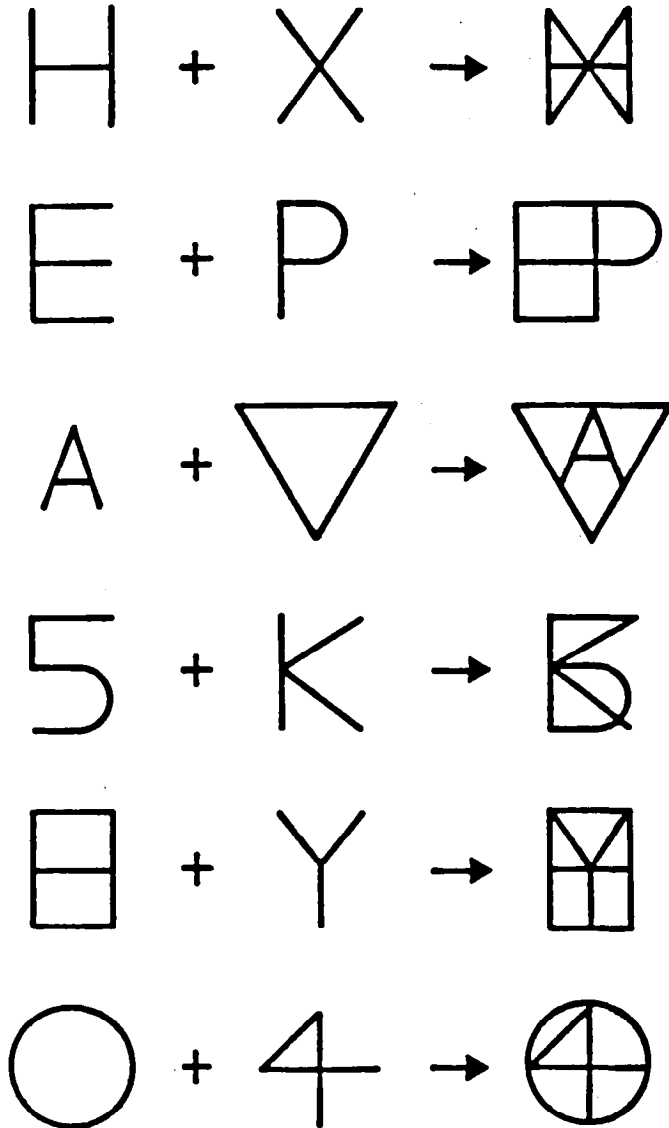


Figure 1. In Experiment 1, subjects were instructed to imagine superimposing or juxtaposing the first two patterns in each row. The patterns shown to the right of the arrows are those that would result if the imagined synthesis were performed correctly.

mental patterns, shown in Figure 1. These were selected on the basis of two criteria: (a) The individual patterns were all familiar, consisting of letters, numbers, or simple geometric forms, making them easy to imagine, and (b) their superposition yielded a pattern that consisted of or contained novel entities associated with conceptual labels. Some of these entities consisted

of simple geometric forms (e.g., "triangle"); others consisted of depictions of objects or figures in some conceptual category (e.g., "butterfly," "the number eight"). The experimenter then instructed the subjects to report any emergent forms that they detected in their images, while always keeping their eyes closed, and then wrote their descriptions down on a response sheet. After the subjects reported that they could not detect any more emergent forms, they were asked to say whether or not they had formed a clear mental image. Following this, they were asked to open their eyes and to draw the final pattern that they had imagined. Then they were asked to inspect their drawing and to report any additional emergent forms that they could now detect but that they hadn't seen in their images. This same procedure was repeated for all six pairs of patterns. The patterns were imagined in random order across the 12 subjects, resulting in a total of 72 imagery reports.

We also asked subjects at the end of the experiment to report whether or not they had any difficulties finding the emergent forms in their images, and if so, to explain what problems they encountered.

Results and Discussion

In scoring the number of emergent forms reported, we adopted conservative conventions. First, only those forms that would *not* have been present in either of the individually described patterns were counted. For example, in the pair in which the letters "H" and "X" were to be combined in an image (see Figure 1), subjects might report detecting the letter "M" and a sideways letter "T," but only the former would be counted as an emergent form. This is because the letter "T" could be detected in the letter "H" alone. In addition, when the same emergent form could appear two or more times in the imagined pattern, reports of that form were counted only once. We also distinguished between geometric and symbolic emergent forms; for example, between reports of detecting "two adjacent squares" and "the number eight." Although we expected that the geometric forms might be easier to detect, reports of symbolic forms might be better examples of reconstructing images, or assigning them new interpretations. Finally, we did not count reports of isolated features (such as "curved lines" or "brackets"), or reports of forms that could not be verified from the subjects' drawings of what they had imagined.

The results showed that an abundance of emergent forms were detected in the constructed images. Summing across all subjects and stimulus patterns, there were 120 reports of geometric forms and 39 reports of symbolic forms during the imagery task. Of the 12 subjects, all 12 reported at least one novel geometric form, and 9 of the 12 reported at least one novel symbolic form. Of the emergent symbolic forms reported, 29 of the reports were of alphanumeric characters, and 10 were of other types of familiar shapes. Some of the more interesting emergent symbolic forms detected in

TABLE 1
Number of Correct Reports of Emergent Patterns in Experiment 1
For Each Pair of Stimulus Patterns

Stimulus Patterns	Type of Emergent Pattern			
	Image		Drawing	
	Geometric	Symbolic	Geometric	Symbolic
"H" + "Y"	16	16	2	7
"E" + "P"	12	8	1	1
"A" + Triangle	22	3	2	6
"5" + "K"	16	4	5	8
Squares + "Y"	39	4	0	4
Circle + "4"	15	4	1	5

Note. The number of reports are summed over the 12 experimental subjects. The emergent patterns reported in the drawings include only those that were not detected in the subjects' mental images.

imagery were a "tilted hourglass" in the "H" and "X" combination, a "5-sided diamond" or "pentagon" in the "A" and "inverted triangle" combination, and a sideways "grain silo" in the "E" and "P" combination. Subjects' drawings revealed that they superimposed the patterns correctly on 68 of the 72 trials, and the subjects reported having formed a clear image 86.1% of the time. The number of different emergent forms based on the images ranged from 8 to 21 across different subjects. The distribution of reports of emergent geometric and symbolic forms for each stimulus pair is presented in Table 1.¹

In sum, we have shown that people are capable of "seeing" shapes in images even when those shapes did not enter into the description or decomposition of the shape initially provided to the subject. We cannot be sure why our findings differ so strongly from those of Reed (1974) and of Reed and Johnsen (1975), who had reported that people are largely unsuccessful at detecting structurally "hidden" forms in imagined patterns. One possibility is that Reed's subjects had to reinterpret, from memory, whole, previously seen patterns that were fairly complex (consisting of 6-16 line segments). Recent experiments by Kosslyn, Reiser, Farah, and Fliegel (1983) have shown that the parts of an image are not generated all at once; instead, it takes a certain amount of time to generate each part. Because the parts begin to fade as soon as they are generated, patterns that cut across several old parts may not be entirely present in an image at a single instant, depending on the total number of parts that must be generated to create the image. Thus in the Reed studies, the initial parsing of the complex pattern into parts

¹ Because the alternative predictions of this experiment were that subjects would report either 0 or more than 0 new construals of the imagined patterns, no relevant statistical analyses can be performed on the data (see also Chambers & Reisberg, 1985).

may have obviated opportunities for the subjects to have detected cross-cutting patterns. In the present experiment, the assembled patterns were relatively simple (consisting of 4–8 line segments).

EXPERIMENT 2

The previous demonstrations of emergent recognition might be limited, however, in one respect. Very few of the emergent symbolic forms corresponded to what might be regarded as reconstructions of the entire pattern. By way of contrast, recall that Chambers and Reisberg (1985) found that textbook examples of ambiguous figures, where the whole pattern would have to be reconstructed, and not just some of its parts, could not be perceptually “reversed” in imagery. Their negative findings suggest that people may not be able to change the entire interpretation of an imagined pattern, although they may still be able to detect some emergent features or parts that they did not anticipate. That is, while people might be capable of verifying aspects of the appearance of an object in an image, they do not have the ability to determine what other interpretations the geometric properties of an imagined shape are capable of supporting, because the image itself contains no information that is not part of a conceptual interpretation.

In Experiment 2, we modified our imagery task to see whether subjects could ever recognize that an entire image corresponded to a familiar form associated with a particular symbol or interpretation that they would not have assigned in advance. We started with a familiar pattern, like a letter or number, and then asked subjects to imagine transforming the pattern until it would correspond to a different pattern which they would be called on to identify.

Method

Subjects. The 12 subjects who participated in Experiment 1 also participated in this experiment, again receiving research credit in an introductory psychology course at Stony Brook.

Procedure. Subjects were told that they would begin each trial by hearing the name of a familiar pattern, whereupon they were to form a mental image of it. The experimenter would then ask them to imagine altering the appearance of the pattern in various ways, and to try to identify the resulting pattern.

As in Experiment 1, two demonstrations were provided to illustrate exactly how the imagery task was to be performed. For example:

Imagine the letter “Q.” Put the letter “O” next to it on the left. Remove the diagonal line. Now rotate the figure 90 degrees to the left. The pattern is the number “8.”

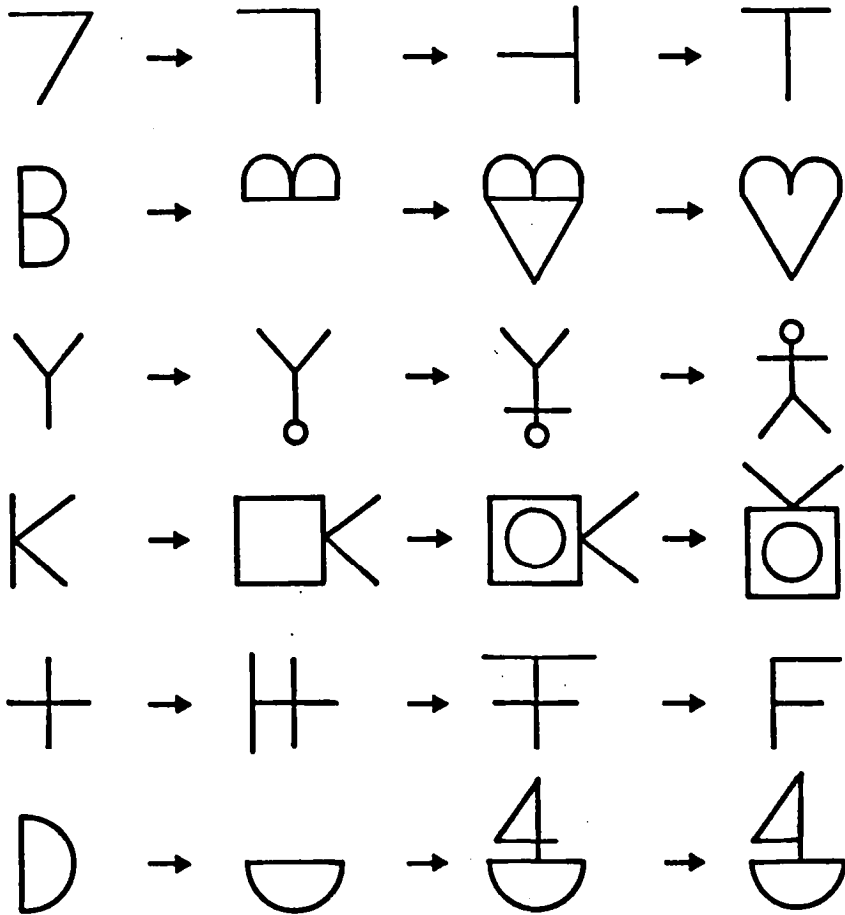


Figure 2. In Experiment 2, subjects were instructed to begin by imagining the patterns shown at the left of each row, and then to imagine transforming the patterns as the illustration depicts. The final patterns in each sequence are the emergent patterns that subjects were to try to recognize. (Descriptions of these sequences that were read to subjects are provided in Table 2.)

There were six image transformation trials for each subject; these are shown in Figure 2. Descriptions for these sequences are presented in Table 2. At the end of the transformation sequence, the experimenter recorded the subject's identification of the final pattern; the correct identifications were, respectively, the letter "T," a "heart," a "stick figure," a "TV set," the letter "F," and a "sailboat." As in Experiment 1, they performed the imagery task while keeping their eyes closed. They were then asked to report whether or not they had formed a clear mental image of the final pattern. After opening their eyes, they were asked to draw the pattern from memory,

TABLE 2
Transformation Sequences Read to Subjects in Experiment 2

"Imagine the number '7'. Make the diagonal line vertical. Move the horizontal line down to the middle of the vertical line. Now rotate the figure 90 degrees to the left." (The letter "T")

"Imagine the letter 'B'. Rotate it 90 degrees to the left. Put a triangle directly below it having the same width and pointing down. Remove the horizontal line." (A heart)

"Imagine the letter 'Y'. Put a small circle at the bottom of it. Add a horizontal line halfway up. Now rotate the figure 180 degrees." (A stick figure)

"Imagine the letter 'K'. Place a square next to it on the left side. Put a circle inside of the square. Now rotate the figure 90 degrees to the left." (A TV set)

"Imagine a 'plus'. Add a vertical line on the left side. Rotate the figure 90 degrees to the right. Now remove all lines to the left of the vertical line." (The letter "F")

"Imagine the letter 'D'. Rotate it 90 degrees to the right. Put the number '4' above it. Now remove the horizontal segment of the '4' to the right of the vertical line." (A sailboat)

Note. See Figure 2 for illustrations of these sequences.

and to try to identify it from the drawing if they did not do so during imagery. This procedure was repeated for all trials. The order of transformation sequences was randomized, and at the end of the experiment the subjects were asked to report any difficulties they might have had transforming their images.

Results and Discussion

The results are presented in Table 3, according to how accurately the imagined transformation was performed, based on the subjects' drawings. A "correct" transformation refers to one that was perfectly correct, a "partial" transformation refers to one that exhibited some minor perturbation or error, but was otherwise accurate, and a "wrong" transformation refers to one that differed substantially from that intended by the description. The identifications were also distinguished according to whether they were correct as intended (the "correct" identifications), clearly wrong (the "incorrect" identifications), or were different from those intended but were also consistent with the final pattern in the sequence (the "alternative" identifications). The latter consisted of reports, for example, of a "double scoop ice cream cone" instead of the "heart," an "upside-down umbrella" instead of the "sailboat," and a "flower with roots" instead of the "stick figure." We report them separately because, though not scored as "correct," they may still be considered legitimate interpretations of the final pattern.

The intended transformations were correctly performed in 59.7% of the trials. As the data in Table 3 indicate, when this was true, subjects correctly identified the emergent symbol 58.1% of the time. Nine out of the 12 subjects made at least one of these correct identifications. Alternative image identifications were made on 11.6% of these trials. Thus when the images

TABLE 3
Emergent Pattern Identifications According to Accuracy of
Mental Transformations in Experiment 2

Pattern Identifications	Accuracy of Transformation		
	Correct	Partial	Wrong
Based on Mental Image			
Correct	25	2	0
Alternative	5	5	0
Wrong	13	8	14
Based on Drawing			
Correct	15	8	0
Alternative	0	0	0
Wrong	3	5	14

Note. Responses are summed across the 12 experimental subjects. Identifications of emergent patterns in the drawings were attempted only when the patterns were not correctly identified in the mental images.

were transformed correctly, an appropriate reconstrual of one sort or another was made 69.7% of the time (and by 10 of the 12 subjects).

Identifications made while inspecting the drawings refer only to those trials on which the pattern was not correctly identified in imagery, but include trials on which an alternative interpretation was given to the imagined pattern. Of the 18 trials on which subjects failed to identify the correct pattern, but had transformed the pattern correctly, correct drawing identifications were made 83.3% of the time. None of the drawing identifications were of the "alternative" variety.

The partial transformations occurred on 20.8% of the trials. Of these, correct image identifications were made only 13.3% of the time, whereas alternative identifications were now made 33.3% of the time. The percentage of correct drawing identifications fell to 53.3%. Counting these correct construals made on the basis of partially flawed images brings the number of subjects who made at least one correct reinterpretation up to 11 out of 12.

The wrong transformations were performed on 19.4% of the trials. It is significant that no correct or alternative identifications were given under these conditions, in contrast to the 63.8% of the trials with correct or partial transformations in which subjects reported a correct or alternative interpretation (this difference is significant, $\chi^2(1) = 17.38$; $p < .01$). This suggests that reports of the target interpretation were contingent on assembling the pattern correctly in the images, and were not the result of anticipations on the basis of the verbal descriptions of the transformations.

The subjects reported having formed clear mental images of the final patterns on 91.7% of the trials. Five of the 12 also reported having had some difficulty mentally rotating the patterns.

Taken together, these results show quite clearly that most subjects, and not necessarily people selected for high spatial or imaginal ability, are capable of understanding a description of a pattern, imagining the pattern according to the description, imagining a specified transformation of the pattern, and then assigning a new interpretation or construal to the entire transformed pattern. We can be confident that this reconstrual was done on the basis of information available in the image, because the construction of the image according to the description had to be performed almost perfectly for the resultant pattern to have been identified correctly. We can thus reject any claim that recognition of emergent patterns in imagery, or reconstrual of an imagined pattern, can never occur.

EXPERIMENT 3

Of course, it is still possible that despite our efforts to disguise what the emergent patterns were going to be, subjects could have been making intelligent guesses about at least some of them, on the basis of knowing what shapes and features were to be combined during the transformation sequence. As a further test of our interpretation of the previous results, we now seek evidence that subjects' ability to reconstrue their images does not depend on their ability to guess, on the basis of information about the features and transformations involved, what the proper reconstruals are likely to be. That is, we seek to ensure that the correct guesses about the identity of the emergent patterns in Experiment 2 could not have been made at some point in the middle of the transformation sequence, using partial information from the first few transformational steps, such as associations to the names of the parts or to the descriptions of the transformation operations, to narrow down the range of possible patterns that could have emerged at the end.

We therefore conducted an experiment similar to Experiment 2, except that now the subjects would be asked to guess what the emergent pattern would be after each step in the transformation sequence. If some emergent patterns are not identified until the final step, we may then rule out, as an alternative explanation, use of a guessing strategy based upon partial information gained after the transformation has begun.

Method

Subjects. A new group of 12 subjects participated, drawn from the same pool as in the previous three experiments.

Procedure. The general procedure was similar to that of Experiment 2, with the following exceptions: First, a new set of six transformation sequences were used; these consisted of three steps as opposed to four, and were structured in such a way that the emergent patterns would be hard to

identify until the very end of the sequence. Also, none of the emergent patterns corresponded to alphanumeric characters, which further reduced the chance of premature correct guessing. Finally, the subjects were specifically instructed to try to guess what the emergent pattern would be after each step. If they correctly identified the emergent pattern prior to the final step, they were asked to explain how they came up with that answer. If they failed to identify the emergent pattern correctly after the final step, they were asked to try to identify it from their drawings.

The two demonstration sequences depicted a square being transformed into a kite, and a circle being transformed into a railroad crossing sign. The six experimental sequences are illustrated in Figure 3, and the corresponding descriptions given to the subjects are presented in Table 4.

Each of the sequences began by naming a letter, which could be upper- or lower-case. In the second step of the transformation, there were three possible rotations, or three possible additions. In the final step, there were two possible rotations, three possible additions, or one deletion. As shown in Figure 3, the emergent patterns symbolized, in order, a musical note, a yield sign (or wine glass), a clock face, an hourglass (or Roman numeral "10"), an umbrella, and a pine tree.

Results and Discussion

Unlike Experiment 2, in this study we did not accept any "alternative" identifications, and only the previously designated symbols counted as "correct" identifications. The number of correct identifications for all sequences, conditions, and levels of transformation accuracy are presented together in Table 5. Of most immediate interest, the emergent patterns were never identified at the end of the first step of the transformation sequence, and were identified only 4.2% of the time at the end of the second step (each based on 72 observations). In the latter case, the only pattern that was correctly anticipated was the hourglass, which is also the only pattern formed simply by a rotation of the pattern immediately preceding it (see again Figure 3). Each of the three subjects who correctly anticipated this pattern reported that he or she had decided to try mentally rotating the second pattern as part of the strategy for guessing. This procedure, therefore, was mostly successful in controlling for the possibility that the emergent patterns might have been identified prior to the final step.

Drawings revealed that the correct transformations were performed on 66.7% of the trials, and of these, the emergent patterns were correctly identified in imagery 47.9% of the time. Eleven of the 12 subjects reported at least one target object. Partial transformations occurred on 19.4% of the trials, and 28.6% of these yielded correct final image identifications. Wrong transformations occurred on the remaining 15.3% of the trials, resulting in only a single correct image identification.

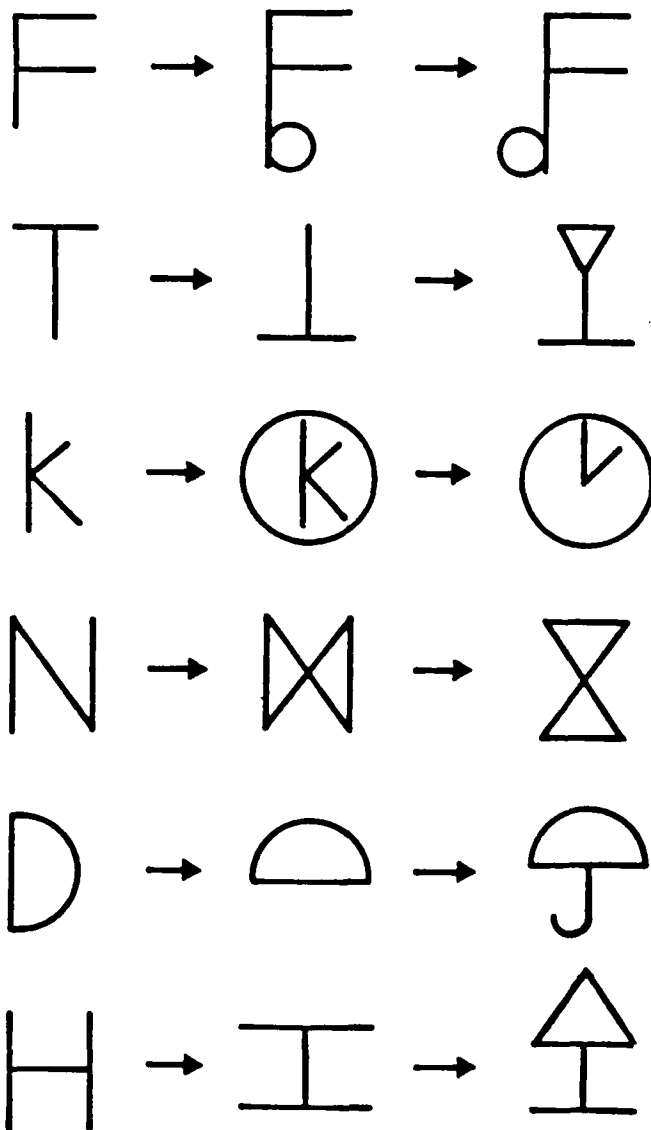


Figure 3. In Experiment 3, subjects were instructed to begin by imagining the patterns shown at the left of each row, and then to imagine transforming the patterns as the illustration depicts. In addition, they were asked to try to guess what the emergent patterns (shown at the right) would be at the end of each step in the transformation sequence. (Descriptions of these sequences that were read to subjects are provided in Table 4.)

Overall, half of the subjects reported having had at least some difficulty inspecting and transforming their images. However, even when the mental transformation was wrong, or only partially correct, there were reports of emergent patterns that, although technically “incorrect” by our scoring

TABLE 4
Transformation Sequences Read to Subjects in Experiment 3

"Imagine a capital letter 'F'. (Guess #1). Connect a lowercase letter 'b' to the vertical line in the 'F'. (Guess #2). Now flip the loop of the 'b' around so that it's now on the left side of the vertical line." (Final Identification).

"Imagine a capital letter 'T'. (Guess #1). Rotate the figure 180 degrees. (Guess #2). Now add a triangle to the top of the figure, positioned so that its base is at the very top and it appears to be pointing down." (Final Identification).

"Imagine a lowercase letter 'k'. (Guess #1). Surround the letter with a circle. (Guess #2). Now remove the lower half of the letter, below the point where the lines intersect." (Final Identification).

"Imagine a capital letter 'N'. (Guess #1). Connect a diagonal line from the top right corner to the bottom left corner. (Guess #2). Now rotate the figure 90 degrees to the right." (Final Identification).

"Imagine a capital letter 'D'. (Guess #1). Rotate the figure 90 degrees to the left. (Guess #2). Now place a capital letter 'J' at the bottom." (Final Identification).

"Imagine a capital letter 'H'. (Guess #1). Rotate the figure 90 degrees to the right. (Guess #2). Now place a triangle at the top, with its base equal in width to that of the figure." (Final Identification).

Note. See Figure 3 for illustrations of these sequences.

criterion, were nevertheless consistent with the distorted final image. For example, one subject, who failed to rotate mentally the letter "H" before adding a triangle on top of it, reported recognizing a "steeple". Another subject, who imagined the lines in the upper half of the lowercase letter "k" to be equal in length and touching the surrounding circle, reported recognizing "a pie with one piece missing."

GENERAL DISCUSSION

The successful identifications in these experiments show that the kind of object a mental image corresponds to need not be assigned during an act of perception, but can also be discovered in the act of transforming and inspecting an image. If so, images must contain enough information about the geometry of a pattern that its category can be assigned after the image is formed, in much the same way that categorial or symbolic descriptions are assigned to visually perceived patterns. Thus, the explanation of Chambers and Reisberg's results cannot be that images are nothing but conceptual interpretations, nor that images lack information about the geometry of a shape that would be necessary for reconstruing it, nor that the information in images is inaccessible to procedures mapping geometric information onto conceptual categories.

Having presented new evidence that reconstruals of images are possible, thus refuting the strong position that images are nothing but interpretations, we turn to Chambers and Reisberg's arguments. In the rest of this

TABLE 5
Emergent Pattern Identifications for Each Transformation Sequence in Experiment 3

Emergent Pattern	Number of Trials	Identification Condition			
		Guess #1	Guess #2	Final Image	Drawing
Correct Transformations					
Musical Note	9	0	0	8	1
Yield Sign	6	0	0	0	3
Clock Face	4	0	0	0	4
Hourglass	10	0	2	2	2
Umbrella	11	0	0	10	1
Pine Tree	8	0	0	1	4
Total	48	0	2	21	15
Partial Transformations					
Musical Note	2	0	0	0	0
Yield Sign	5	0	0	2	1
Clock Face	4	0	0	1	1
Hourglass	1	0	1	0	0
Umbrella	0	0	0	0	0
Pine Tree	2	0	0	0	1
Total	14	0	1	3	3
Wrong Transformations					
Musical Note	1	0	0	0	0
Yield Sign	1	0	0	1	0
Clock Face	4	0	0	0	0
Hourglass	1	0	0	0	0
Umbrella	1	0	0	0	0
Pine Tree	2	0	0	0	1
Total	10	0	0	1	1

Note. Responses are summed across the 12 experimental subjects. Identifications of emergent patterns in the drawings were attempted only when the patterns were not correctly identified in the mental images.

paper, we will ask whether our experiments are valid tests of the hypothesis that image reconstrual is impossible, and whether the philosophical arguments cited by Chambers and Reisberg establish that images are not reinterpretable. Finally, we examine why certain kinds of image reconstrual, such as reversals of duck/rabbits and Necker cubes, do not seem to be possible, whereas other kinds, such as those involving a rotated-D + J/umbrella or a rotated-N/Z, are possible.

Processing Geometric Information in Images versus Assigning a New Interpretation to Images: A Valid Distinction?

There are two reasons why proponents of Chambers and Reisberg's view might not accept subjects' performance in these experiments as legitimate

examples of reversing an ambiguous figure in imagery. The first is that in our experiments, unlike those of Chambers and Reisberg, subjects were not given a single figure that could be described in two ways and then asked to discover the second description in imagery. Instead, they were told to construct a figure piece by piece, and only the resulting pattern had a simple description. Thus, one might say, there could be no reconstrual in these experiments, because there was no initial construal that had to be switched away from.

In fact, such an objection does not apply. All of the stimuli used in these experiments had at least two interpretations or construals, for example, "H and X superimposed" versus "butterfly"; "inverted Y with a circle and crossbar attached" versus "stick figure"; "F with a mirror-reversed b attached" versus "musical note"; and so on. Furthermore, in each of these cases the subject started out with only one of these interpretations (since the images were constructed on the basis of those interpretations) and in successful cases "switched to" or "saw" the alternative one. The fact that one of the two interpretations was invariably characterized by a complex articulated description rather than by a single word, unlike the case of a duck/rabbit, is of little theoretical importance. There is no basis for considering the patterns used in this experiment to be any less ambiguous than the duck/rabbit, especially since we can be sure that the complex description had to have been psychologically real or entertained by the subjects in some way in order for them to have created the appropriate image. For that matter, some of the ambiguous figures used by Chambers and Reisberg, such as the Necker cube and Schroeder staircase, also do not have one-word labels attached to each interpretation.

The main value of the traditional reversible figures is that in general, at least one of the interpretations is not perceived immediately (for reasons we will discuss later). Thus, the reversal is surprising to the perceiver (and hence is a provocative demonstration of perceptual ambiguity), and an experimenter can be confident that in an image reconstrual experiment, the subject was not aware of both interpretations when the figure was first perceived. But in our experiments, figures were provided to the subject via verbal descriptions that afforded no opportunity for the subject to detect the second interpretation before the image was completed. Since the patterns were never physically presented to the subjects, there is no need to worry that both construals could have been made during perception. Therefore, the fact that our stimuli do not contain two simply characterized but mutually incompatible descriptions is of no concern. As Chambers and Reisberg point out (p. 319), "the critical test of whether images can be reconstrued hinges on whether subjects can *discover* an unanticipated, uncued shape in an image" [emphasis theirs]. That is precisely what we have demonstrated.

The second possible objection to our results can already be found in their paper when they discuss the earlier demonstrations of the detection of novel

patterns in images (e.g., Pinker & Finke, 1980; Reed, 1974; Slee, 1980; and by extension, Shepard and Feng). These demonstrations are all clearly incompatible with the strongest position that one could take on the issue (a position they associate with Fodor, 1981, and Casey, 1976), namely that images are nothing but symbols of a particular thing, so there is no issue of "reading" or "interpreting" an image, because the interpretation must be there at the outset. The reason that even Chambers and Reisberg must distance themselves from this strongest view is that nothing in the *interpretation* of the letter "M" (e.g., that it is the grapheme for the phoneme /m/, the 13th letter of the alphabet, or the first letter in *mother*) allows one to determine that it is also an inverted "W." Similarly, nothing in the interpretation of two adjacent "X"s allows one to determine that a diamond is embedded in it, and nothing in the interpretation of a "J" affixed to a sideways "D" allows one to determine that it depicts an umbrella. Rather, it is the geometry of the pattern that allows these inferences to be made. Since these inferences *can* be made, subjects must have more than the pure symbolic or conceptual residue of these visual patterns available to them.

Chambers and Reisberg deal with this problem by conceding to the imagery system some ability to process geometric information that nonetheless falls short of the ability to construe or reconstrue a pattern. Specifically, they attribute subjects' performance in supposedly reinterpreting images to a two-stage process of replacement or alteration of an initial image, yielding a new distinct image, followed by detection of an isomorphism between the original image and the altered or new one. For example, subjects don't actually see a parallelogram in an image of two adjacent Roman numeral 10's; they start off with an image of a parallelogram, and add or replace parts of it until a form isomorphic to the two juxtaposed Roman numerals results. This "isomorphism," the fact that the two images "have a common form," is detected, and possibly confirmed by exchanging the two distinct images ("parallelogram with segments added" versus "adjacent Roman numeral 10's") and verifying the commonness of form.

There are two reasons why this argument would not work here. First, in experimental paradigms such as ours, in which subjects are not asked to verify the presence of a given pattern but to report *any* pattern that they see, the subject would be required to arrive at an image isomorphic to the target image by a process of trial and error. Regardless of how likely that might have been in earlier studies, it is out of the question in the present demonstrations, where the alternative interpretations of the forms were not supplied to the subjects for verification or even guessed by the subjects before their images were complete. We can safely estimate that there is a near-zero probability that subjects randomly selected a musical note, a TV set, or an umbrella to test for isomorphism with permuted images of F's, K's, circles, and J's in just the cases where we designed the patterns to correspond to these figures.

But even if subjects somehow manage to select the appropriate target figure to juxtapose with the first image, they still have to represent enough

information about the geometry of the two images that isomorphic shapes can be recognized as such, and this information has to be fed into a process that can detect isomorphism. Chambers and Reisberg are willing to attribute this ability—detection of “isomorphism” or “common form”—to the imagery system. They also concede that people can detect “unanticipated particulars” in an image; that “one can also be surprised by relations inside an image,” such as the size of an image and the color of its background; and that one must “inspect the image to learn how it appears.” They refer to an “imagery medium” that allows one to assess the appearance of images, and say that “imagery and perception seem to share a mode of representation, a mode that respects the metric properties of space.” Furthermore, images include information about figure and ground, orientation, and depth relations. Chambers and Reisberg are vague as to what exactly they claim the imagery system can do, but it is clear that in these passages they do not deny that it can represent and process some kinds of geometric information concerning the appearance of a figure.

The problem is that one cannot both attribute these properties to the imagery system and also deny that it is possible to construe or reconstrue an image, that is, to determine what categories of objects the image depicts. That is because representing geometric information about an object, and being able to verify whether particular geometric configurations are present, is in general a sufficient condition for construal to take place. The process of assigning a particular description, interpretation, or construal to an object in perception is nothing but representing the geometric properties of the visual input and determining whether certain relations are satisfied; Marr (1982) even defines the function of the visual system as deriving a description of the world via computations on the geometry of the optical input. For example, construing a pattern of lines as an example of the letter “A” involves determining whether two of the lines form an upward-pointing angle and the third one joins them part way down their lengths. Barring telepathy, what else could construal in perception be? So if the imagery system can represent and submit to analysis the spatial configuration of a pattern, there is nothing to prevent it from assigning an interpretation, including a new interpretation, to that pattern, by applying some of the same processes that are used at some stage of perception. If one can represent in an image the information that a pattern consists of two lines forming an upward-pointing angle, and a third horizontal line joining them midway down their lengths, and can access that information (as Chambers and Reisberg appear willing to concede), there is nothing to prevent one from assigning, as one does in perception, the description “/a/, the first letter in the alphabet” to that pattern, even if such a description was not in mind when the image was first formed. And that is exactly what our subjects did.

In sum, Chambers and Reisberg attempt to remove themselves from this dilemma by drawing a distinction where no distinction can be drawn. If they hold to the extreme view that images are nothing but symbolic descriptions

or construals, with geometric information sloughed off or inaccessible, they cannot account for people's ability to detect new patterns in an image or to verify that a part is present in an image. On the other hand, if they allow that images preserve geometric information, and attribute to the imagery system the power to inspect images to learn how they appear, to detect commonality of form between two images, or to note and be surprised by relations inside an image, they cannot maintain that it lacks the ability to assign a novel interpretation to an image, because assigning an interpretation to a pattern is nothing but the ability to detect relations and properties in the appearance of an object and determining the commonality of form with representations stored in memory.

What's Wrong with the Philosophical Arguments against the Possibility of Image Reconstrual²

Chambers and Reisberg cite arguments from the philosophical literature (e.g., Casey, 1976; Fodor, 1981); that they interpret as saying that (p. 318) "there is no issue of 'reading' or 'interpreting' an image. The image is created as a symbol of some particular thing, and so the interpretation is there at the outset. . . . without a construal process, there is no possibility for reconstrual." We argue that their claim collapses two points, one conceptual and one empirical, and is based on a hidden and dubious premise. The *conceptual* point made by Fodor (which he attributed to Wittgenstein) is that images are only capable of representing by virtue of their being interpreted entities, not because of their being "pictorial" and hence "resembling" external objects. (The problem is that pictures are inherently ambiguous in terms of what they *could* represent: a picture of Richard Nixon could be a representation of Nixon, of a president, of a man, etc.). We have no quarrel with this point. The *hidden premise*, which is what allows Chambers and Reisberg to use this conceptual argument to make claims about the empirical nature of imagery, is that if an entity is *interpreted*, it cannot be *reinterpreted*. This leads them to the *empirical* claim that mental images in fact cannot be reinterpreted. Note that without the hidden premise, the conceptual point would not motivate the empirical claim.

The problem with the argument is that there is no basis for the hidden premise that an interpreted entity is in principle incapable of being reinterpreted. Interpreted entities could indeed be reinterpreted, if they had both an uninterpreted aspect or part and an interpreted aspect or part, and if the uninterpreted aspect or part contained enough information that the original interpreted aspect or part could be replaced by a new one. To take a crude example, an image could be an interpreted entity by virtue of its consisting of a picture plus a caption, the caption being the interpretation. If the picture contained the requisite information and was accessible to a suitable process,

² We are grateful to Ned Block for his assistance in formulating the arguments in this section.

a new caption could be put in place of the old one. On the other hand, to take an equally crude example, an image could be nothing but a sentence summarizing the interpretation. In that case, the geometric information necessary to replace the sentence with another one consistent with the represented object may be absent, and reinterpretation would be impossible. Both of these examples are consistent with the claim that images represent by virtue of their being interpreted entities. In other words, there may exist two kinds of interpreted entities: those that can be reinterpreted and those that cannot. Whether human visual images are of the first kind or the second kind is strictly an empirical question.³

The point can be made without talking about pictures in the head. Consider two machines. Both of them have video cameras aimed at checkerboards. Both register the distribution of light intensities in the projections of the checkerboards by storing them digitally in a "bit map" memory. Both have algorithms that can take as input the information in the bit maps, and use that information to verify whether certain geometric patterns are instantiated by the pattern of checkers in the scene; for example, whether they constitute an example of the letter "X." An assertion to that effect could be stored in memory, and in a sense would serve as an "interpretation" of the checkerboard pattern. When the checkerboard is removed from the camera's view, however, one machine erases its bit map and the other stores it in a file. Later, the machines are called on to determine whether some new object was instantiated in the now-absent checkerboard (i.e., whether it can be given a new interpretation), for example, a tilted "+" (assuming that "+"s are "X"s whose segments meet at right angles.) The second machine can retrieve its bit map, allow its geometric property-verification algorithms to process the information in it, determine the answer, and store it as a new interpretation. The first machine is incapable of this. (It would also be unable to detect the "+" if it had recorded the bit map but was incapable of retrieving it and feeding it into the verification algorithm. Note also that for the purposes of this example, the arrangement of checkers and the pattern in question could be anything whatsoever—such as a duck/rabbit.) Clearly, one can ask whether the human capacity for recalling and recognizing visual patterns more closely resembles the capabilities of the first machine or the second machine, and the question of people's ability to reconstrue an image is basically a version of this conceptually straightforward question.

To summarize, the inherent ambiguity of pictures makes them unsuitable to serve by themselves as representations of objects. Therefore images, if

³ One could state that once an image is reinterpreted (say, once the picture gets a new caption), it becomes a *new* image. That is, our experimental phenomena *must* have consisted of subjects replacing one image with another, because an image with a new interpretation must be a new image; the old one would be gone. But this statement would just be a stipulation of what the word "image" is allowed to mean, and would have no relevance to the scientific issue of the nature of the mechanisms underlying imagery.

they represent, must consist of or contain interpretations. These are conceptual points that we do not argue with. However, images may or may not be the kind of interpreted entity that is susceptible to *re*interpretation. This is an empirical question, and our experiments show that the answer to it is that such reinterpretation is possible.

Why Don't Classical Ambiguous Figures Reverse in Imagery?

We have tried to show that Chambers and Reisberg do not have a clear interpretation of their findings: The claim that visual images cannot ever be given new construals, because they contain no accessible uninterpreted geometric information, is empirically false, and the middle ground they attempt to occupy, in which images contain accessible geometric information but nonetheless cannot be reinterpreted, is logically inconsistent. However, we do not wish to diminish the value of their empirical demonstrations that classical ambiguous figures cannot be reversed when imagined. Though our experiments show that the strongest negative claims cannot be maintained, Chambers and Reisberg's findings still demand an interpretation. (Furthermore, there are other reasons to suspect that there are limitations on people's power of reconstrual: In experiments on mental superimposition of visual parts such as Palmer (1977) and Thompson and Klatzky (1978), the mentally synthesized emergent shape generally does not attain the same holistic status in perception as when that shape was actually presented to subjects visually.)

One possibility is that there is no principled difference between the classical ambiguous figures and our transformed patterns, and that the empirical differences are due either to confounded factors, such as the complexity of the Necker cube and the Schroeder staircase, or the salience and succinctness of the labels for each interpretation of the duck/rabbit, giving rise to Stroop-like interference blocking the reinterpretation. However, it is difficult to motivate an account based on such factors, and for what it is worth, most observers note that the process of trying to reverse classical ambiguous figures "feels" different from the processes involved in our demonstrations. Thus, it is possible that the two kinds of reconstrual are different for principled reasons. Here we suggest one possibility.

What is distinctive about classic ambiguous figures? First, it is difficult for perceivers to reverse the figures at will (though they can influence the likelihood of a reversal by shifting attention to one or another part of the figure.) Second, it is not just the interpretation of the entire figure that changes, but the representation of the geometric disposition of each of the features of the figure (which are also ambiguous) that changes as well. For example, in the duck/rabbit figure, the directions of the object's front-back and top-bottom axes with respect to the viewer's axes change in the reversal: The duck is typically pointing up and to the right, whereas the rabbit points

down and to the left, and the paired appendages are at the front of the duck pointing in its frontward direction but at the top of the rabbit pointing up and back. In the Necker cube, there is also a reassignment of the objects' axes with respect to the viewer: Some convex edges and vertices become concave and vice versa, and the relative distances of each segment from the viewer change. In the Schroeder staircase, this happens as well, and there is, in addition, a figure-ground reversal and a shift of the boundaries between major parts (see Hoffman & Richards, 1984).

In a naturalistic, visual environment these features can often be assigned by bottom-up analysis alone (using stereopsis, for example), but in line drawings the features are all locally ambiguous, and are thought to be resolved by global constraints on the coherence of the object as a whole. Multiple crude analyses of both parts and wholes are computed simultaneously, and those tentative representations for parts that are consistent with certain tentative representations for the whole mutually reinforce each other to the exclusion of all other analyses in a "cooperative" or "relaxation" process (Attneave, 1971; Feldman & Ballard, 1982; Hinton, 1981). For example, the lowermost horizontal edge of a Necker cube can be represented as convex if and only if the leftmost vertical edge is represented as convex and if and only if the cube is represented as being viewed from above. For ambiguous figures, two global representations are possible, each with a consistent set of representations of the parts. It is assumed that they mutually inhibit each other and thus one global representation dominates, reinforces one set of part representations, and then fatigues, allowing the other global representation to dominate and thus boost the alternative representations for each of its parts. Thus, reversals involve a set of simultaneous mutually consistent changes in the representations of the geometric properties of the parts of the objects relative to the object, and of the object relative to the viewer.

The reconstrued patterns in the present experiments, however, had the assignments of the relative dispositions of their features specified during the verbal descriptions. Thus although our subjects had to reassign the *conceptual* interpretation of each part, they did not have to switch the assignments of *geometric dispositions* of each of the parts by using compatibility relations with each other and with the global object. For example, subjects were told to rotate a "D" counterclockwise and put it on top of a "J"; this specifies the representation of the direction and location of the semicircle in a way that is compatible with the interpretation required by the construal of the object as a depiction of an umbrella. Subjects had to be able to interpret the resulting collection of parts as an exemplar of a different conceptual category, but they did not have to reverse figure and ground, convex and concave, or near and far for each of the features of the pattern.

This difference could be the critical factor distinguishing our results from those of Chambers and Reisberg, for two possible reasons. One is that the

global resolution of local geometric ambiguity may require that the whole pattern be active at one time in the visual representation; images, in contrast, consist of dynamically fading and regenerated parts (Kosslyn, 1975; Kosslyn et al., 1983).⁴ The other is that the positive feedback loop that resolves local geometric ambiguities may occur at an early stage of visual representation preceding the stage at which memory-generated information can be inserted to create a visual image. Marr (1982), Ullman (1984), Treisman and Gelade (1980), and Pinker (1984), for example, distinguish between "early" or "low-level" vision, and "late" or "high-level" vision. Low-level vision is assumed to go on automatically and independently of the perceiver's goals or beliefs, to consist of parallel processing across the entire visual field, and to output a representation consisting of the values of a small set of local features for every location in the visual field. "High-level" vision can depend on the goals and knowledge of the perceiver, and it consists of "routines" that apply within an attentional "spotlight" moved sequentially over the visual field in order to detect the presence of feature conjunctions, global and topological properties, and entire objects. Many of the feature representations that reverse in classical ambiguous figures, such as disposition relative to the viewer and the object, convexity versus concavity, figure versus ground, and major part boundaries, are probably computed by early visual processes, which would include the global disambiguation process discussed above. Imagery, on the other hand, does not seem to extend down to these early, automatic visual processes, but interacts with higher level visual routines (see Finke, 1987; Jolicoeur, Ullman, & Mackay, 1986; Pinker, 1984; and Ullman, 1984, for general reviews, and Pinker, 1980, and Pinker & Finke, 1980, for evidence that, specifically, images occur after the stage in which three-dimensional information is assigned). Thus the nonreversibility of classical ambiguous figures in imagery may be due not to images lacking nonconceptual geometric information, which we have shown is false, but to images being unable to affect the low-level process that uses global object consistency to disambiguate the basic geometric properties of local features.

⁴ Chambers and Reisberg consider a simpler version of this possibility, and dismiss it based on the results of Hochberg's (1970) demonstration that subjects can reverse ambiguous figures under anorthoscopic viewing conditions, that is, when they see only a portion of the figure at a time as the figure is moved behind a narrow slit. This finding is cited as evidence that reconstruction can take place when subjects have only piecemeal access to the parts of a figure. However, anorthoscopic perception is achieved only when the figure moves behind a viewing window above a certain critical speed, and is a topic of interest in the psychology of vision precisely because under these conditions subjects do not mentally glue together separately perceived parts, but rather perceive a whole figure via the application of an automatic, low-level perceptual process. This contrasts with what is known about the structure of mental images, which are generated and maintained a part at a time (see Kosslyn, 1980, Chapters 6 and 7).

The accounts discussed above are by no means definitive; additional research on these two complex and poorly understood processes (image generation and global disambiguation) and their interaction is needed. However, we hope to have shown not only that images maintain enough geometric information to support conceptual reconstrual, but to have made a more general point as well. One problem with debates over visual imagery is that imagery and perception are treated as monolithic entities, and coarse common sense notions such as "construal" or "interpretation" are applied categorically to them. As we have argued elsewhere (see Farah, 1984; Finke, 1980, 1987; Pinker, 1984), such an approach will inevitably lead to the appearance of paradoxes. This can be avoided if one assumes that imagery, like perception, consists of a set of distinct information processing stages, each dedicated to a different level or type of analysis.

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