

Features and Objects in Visual Processing

The seemingly effortless ability to perceive meaningful wholes in the visual world depends on complex processes. The features automatically extracted from a scene are assembled into objects

by Anne Treisman

If you were magically deposited in an unknown city, your first impression would be of recognizable objects organized coherently in a meaningful framework. You would see buildings, people, cars and trees. You would not be aware of detecting colors, edges, movements and distances, and of assembling them into multidimensional wholes for which you could retrieve identities and labels from memory. In short, meaningful wholes seem to precede parts and properties, as the Gestalt psychologists emphasized many years ago.

This apparently effortless achievement, which you repeat innumerable times throughout your waking hours, is proving very difficult to understand or to simulate on a computer—much more difficult, in fact, than the understanding and simulation of tasks that most people find quite challenging, such as playing chess or solving problems in logic. The perception of meaningful wholes in the visual world apparently depends on complex operations to which a person has no conscious access, operations that can only be inferred on the basis of indirect evidence.

Nevertheless, some simple generalizations about visual information processing are beginning to emerge. One of them is a distinction between two levels of processing. Certain aspects of visual processing seem to be accomplished simultaneously (that is, for the entire visual field at once) and automatically (that is, without attention being focused on any one part of the visual field). Other aspects of visual processing seem to depend on focused attention and are done serially, or one at a time, as if a mental spotlight were being moved from one location to another.

In 1967 Ulric Neisser, then at the

University of Pennsylvania, suggested that a "preattentive" level of visual processing segregates regions of a scene into figures and ground so that a subsequent, attentive level can identify particular objects. More recently David C. Marr, investigating computer simulation of vision at the Massachusetts Institute of Technology, found it necessary to establish a "primal sketch": a first stage of processing, in which the pattern of light reaching an array of receptors is converted into a coded description of lines, spots or edges and their locations, orientations and colors. The representation of surfaces and volumes and finally the identification of objects could begin only after this initial coding.

In brief, a model with two or more stages is gaining acceptance among psychologists, physiologists and computer scientists working in artificial intelligence. Its first stage might be described as the extraction of features from patterns of light; later stages are concerned with the identification of objects and their settings. The phrase "features and objects" is therefore a three-word characterization of the emerging hypothesis about the early stages of vision.

I think there are many reasons to agree that vision indeed applies specialized analyzers to decompose stimuli into parts and properties, and that

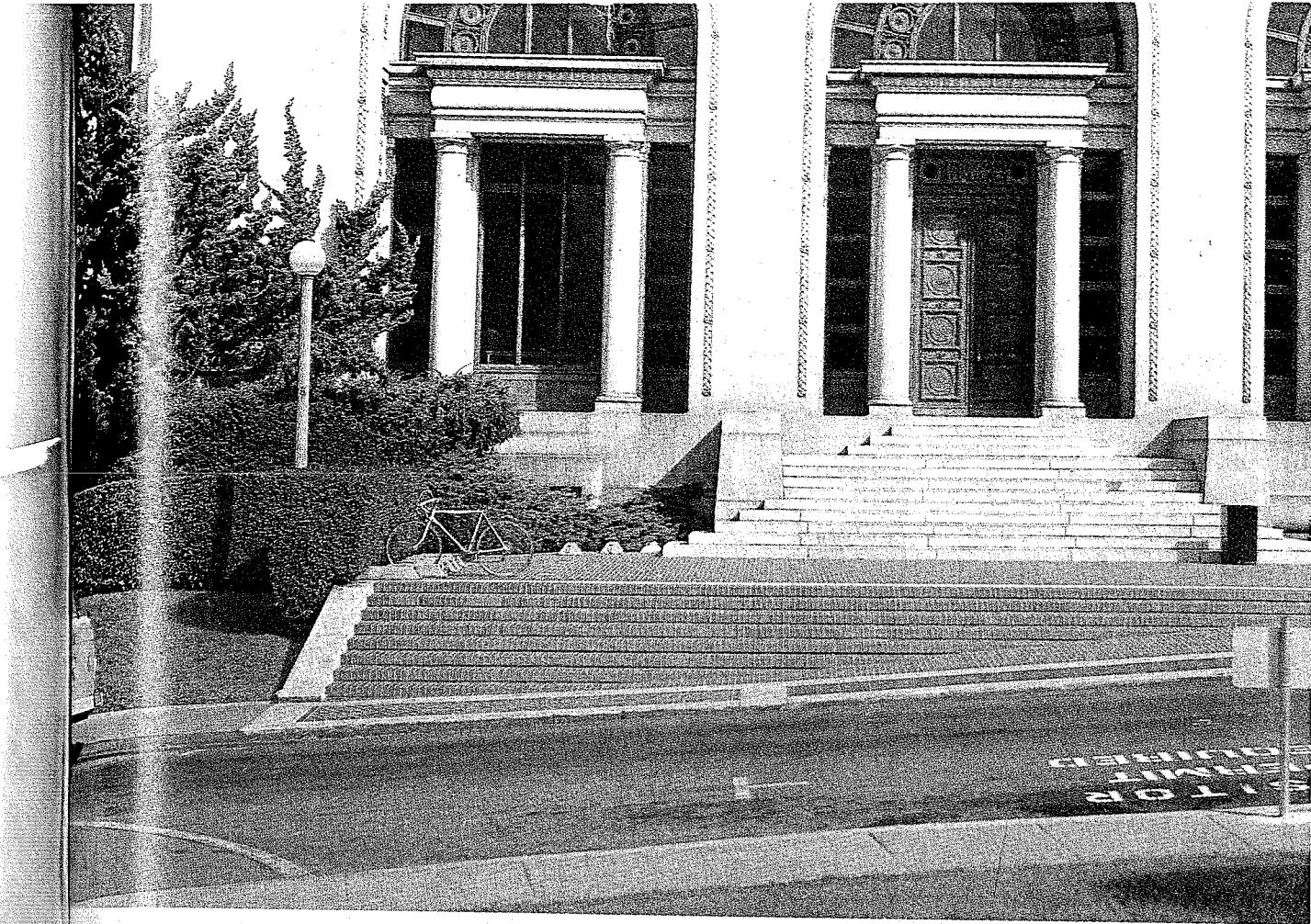
extra operations are needed to specify their recombination into the correct wholes. In part the evidence is physiological and anatomical. In particular, the effort to trace what happens to sensory data suggests that the data are processed in different areas of considerable specialization. One area concerns itself mainly with the orientation of lines and edges, another with color, still another with directions of movement. Only after processing in these areas do data reach areas that appear to discriminate between complex natural objects.

Some further evidence is behavioral. For example, it seems that visual adaptation (the visual system's tendency to become unresponsive to a sustained stimulus) occurs separately for different properties of a scene. If you stare at a waterfall for a few minutes and then look at the bank of the river, the bank will appear to flow in the opposite direction. It is as if the visual detectors had selectively adapted to a particular direction of motion independent of *what* is moving. The bank looks very different from the water, but it nonetheless shows the aftereffects of the adaptation process.

How can the preattentive aspect of visual processing be further subjected to laboratory examination? One strategy is suggested by the obvious fact that in the real world parts that belong to the same object tend to share prop-

PRIOR KNOWLEDGE AS A GUIDE in visual perception is tested by asking subjects to search for a familiar object in a photograph of an unexceptional scene (*top*) or in a jumbled photograph of the scene (*bottom*). Here the task is simply to find the bicycle. It tends to take longer in the jumbled image. The implication is that knowledge of the world (in this case expectations about the characteristic locations of bicycles in an urban landscape) speed up perception and make it less subject to error. Certain early aspects of the information processing that underlies visual perception nonetheless seem to happen automatically: without the influence of prior knowledge. The illustration was modeled after experiments done by Irving Biederman of the State University of New York at Buffalo.

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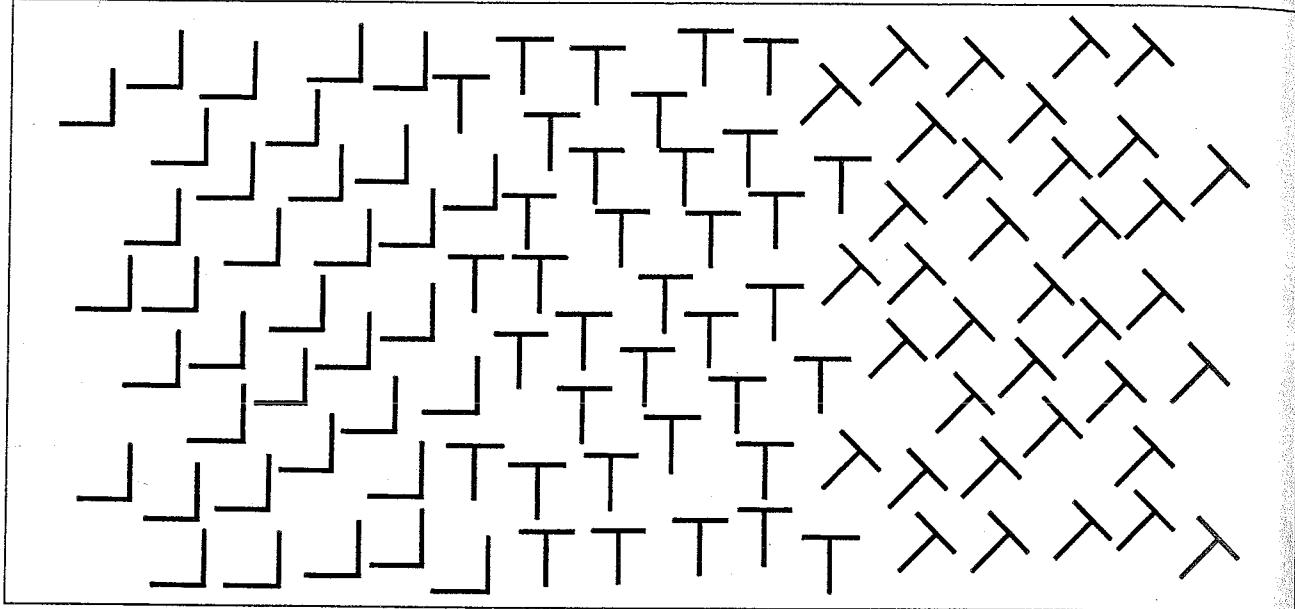
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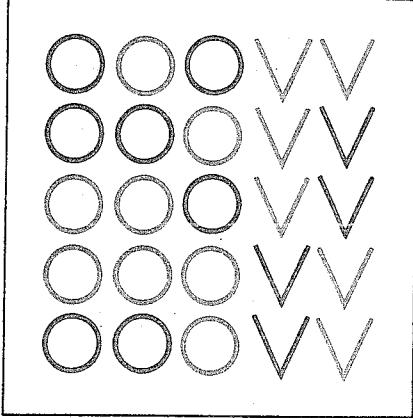
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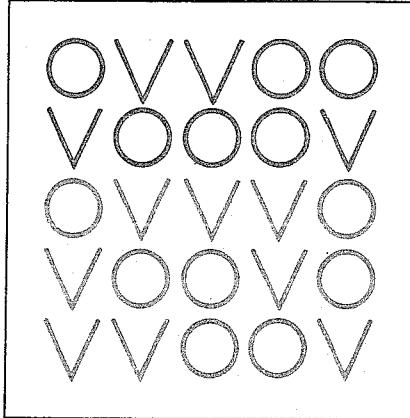
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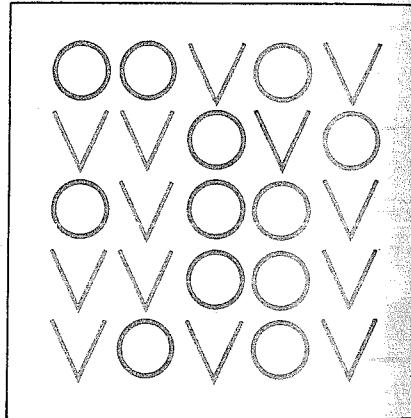
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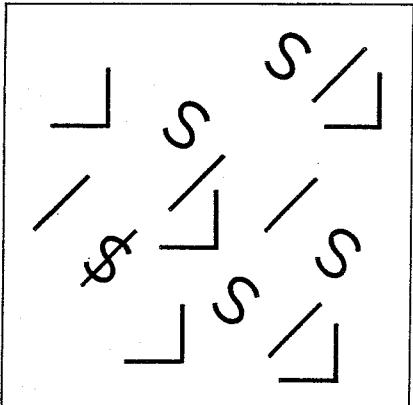
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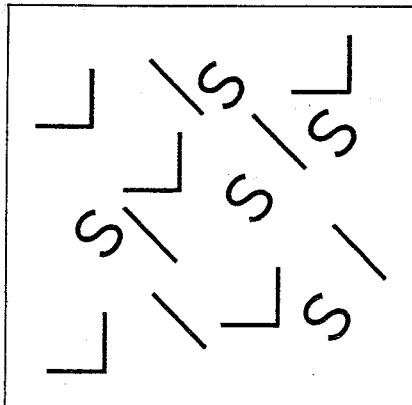
BOUNDARIES THAT "POP OUT" of a scene are likely to reveal the simple properties, or features, of the visual world that are seized on by the initial stage of visual processing. For example, a boundary between T's and tilted T's pops out, whereas a boundary between T's and L's does not (a). The implication is that line orientations are important features in early visual processing but that particular arrangements of conjunctions of lines are not. A

boundary between O's and V's pops out (b). The implication is that simple shape properties (such as line curvature) are important. A boundary between red and blue shapes pops out (c), implying that color is important. A boundary between conjunctions of shape and color, in this case red V's and blue O's versus red O's and blue V's (d), does not pop out. Evidently early vision deals only with individual features, not with conjunctions of features.

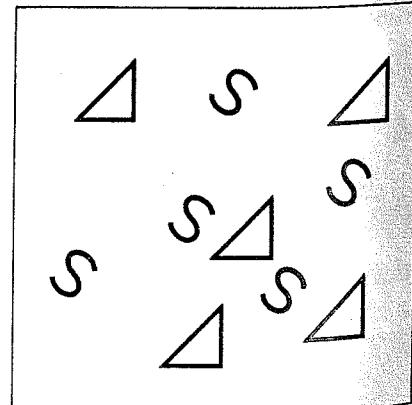
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ILLUSORY DOLLAR SIGNS are an instance of false conjunctions of features. Subjects were asked to look for dollar signs in the midst of S's and line segments (a). They often reported seeing the signs when the displays to which they were briefly exposed

contained none (b). They had the same experience about as often when the line segment needed to complete a sign was embedded in a triangle (c). The experiment suggests that early visual processing can detect the presence of features independent of location.

erties: they have the same color and texture, their boundaries show a continuity of lines or curves, they move together, they are at roughly the same distance from the eye. Accordingly the investigator can ask subjects to locate the boundaries between regions in various visual displays and thus can learn what properties make a boundary immediately salient—make it “pop out” of a scene. These properties are likely to be the ones the visual system normally employs in its initial task of segregating figure from ground.

It turns out that boundaries are salient between elements that differ in simple properties such as color, brightness and line orientation but not between elements that differ in how their properties are combined or arranged [see top illustration on opposite page]. For example, a region of T's segregates well from a region of tilted T's but not from a region of L's made of the same components as the T's (a horizontal line and a vertical line). By the same token, a mixture of blue V's and red O's does not segregate from a mixture of red V's and blue O's. It seems that the early “parsing” of the visual field is mediated by separate properties, not by particular combinations of properties. That is, analysis of properties and parts precedes their synthesis. And if parts or properties are identified before they are conjoined with objects, they must have some independent psychological existence.

This leads to a strong prediction, which is that errors of synthesis should sometimes take place. In other words, subjects should sometimes see illusory conjunctions of parts or properties drawn from different areas of the visual field. In certain conditions such illusions take place frequently. In one experiment my colleagues and I flashed three colored letters, say a blue X, a green T and a red O, for a brief period (200 milliseconds, or a fifth of a second) and diverted our subjects' attention by asking them to report first a digit shown at each side of the display and only then the colored letters. In about one trial in three the subjects reported the wrong combinations—perhaps a red X, a green O or a blue T.

The subjects made these conjunction errors much more often than they reported a color or shape that was not present in the display, which suggests that the errors reflect genuine exchanges of properties rather than simply misperceptions of a single object. Many of these errors appear to be real illusions, so convincing that subjects demand to see the display again to convince themselves that the errors were indeed mistakes.

We have looked for constraints on the occurrence of such illusory conjunctions. For example, we have asked whether objects must be similar for their properties to be exchanged. It seems they do not: subjects exchanged colors between a small, red outline of a triangle and a large, solid blue circle just as readily as they exchanged colors between two small outline triangles. It is as if the red color of the triangle were represented by an abstract code for red rather than being incorporated into a kind of analogue of the triangle that also encodes the object's size and shape.

We also asked if it would be harder to create illusory conjunctions by detaching a part from a simple unitary shape, such as a triangle, than by moving a loose line. The answer again was no. Our subjects saw illusory dollar signs in a display of S's and lines. They also saw the illusory signs in a display of S's and triangles in which each triangle incorporated the line the illusion required [see bottom illustration on opposite page]. In conscious experience the triangle looks like a cohesive whole. Nevertheless, at the preattentive level its component lines seem to be detected independently.

To be sure, the triangle may have an additional feature, namely the fact that its constituent lines enclose an area, and this property of closure might be detected preattentively. If so, the perception of a triangle might require the detection of its three component lines in the correct orientations and also the detection of closure. We should then find that subjects do not see illusory triangles when they are given only the triangles' separate lines in the proper orientations. They may need a further stimulus, a different closed shape (perhaps a circle), in order to assemble illusory triangles. That is indeed what we found.

Another way to make the early, preattentive level of visual processing the subject of laboratory investigation is to assign visual-search tasks. That is, we ask subjects to find a target item in the midst of other, “distractor” items. The assumption is that if the preattentive processing occurs automatically and across the visual field, a target that is distinct from its neighbors in its preattentive representation in the brain should “pop out” of the display. The proverbial needle in a haystack is hard to find because it shares properties of length, thickness and orientation with the hay in which it is hidden. A red poppy in a haystack is a much easier target; its unique color and shape are detected automatically.

We find that if a target differs from

the distractors in some simple property, such as orientation or color or curvature, the target is detected about equally fast in an array of 30 items and in an array of three items. Such targets pop out of the display, so that the time it takes to find them is independent of the number of distractors. This independence holds true even when subjects are not told what the unique property of the target will be. The subjects take slightly longer overall, but the number of distractors still has little or no effect.

On the other hand, we find that if a target is characterized only by a conjunction of properties (for example, a red O among red N's and green O's), or if it is defined only by its particular combination of components (for example, an R among P's and Q's that together incorporate all the parts of the R), the time taken to find the target or to decide that the target is not present increases linearly with the number of distractors. It is as if the subjects who are placed in these circumstances are forced to focus attention in turn on each item in the display in order to determine how the item's properties or parts are conjoined. In a positive trial (a trial in which a target is present) the search ends when the target is found; on the average, therefore, it ends after half of the distractors have been examined. In a negative trial (in which no target is present) all the distractors have to be checked. As distractors are added to the displays, the search time in positive trials therefore increases at half the rate of the search time in negative trials.

The difference between a search for simple features and a search for conjunctions of features could have implications in industrial settings. Quality-control inspectors might, for example, take more time to check manufactured items if the possible errors in manufacture are characterized by faulty combinations of properties than they do if the errors always result in a salient change in a single property. Similarly, each of the symbols representing, say, the destinations for baggage handled at airline terminals should be characterized by a unique combination of properties.

In a further series of experiments on visual-search tasks, we explored the effect of exchanging the target and the distractors. That is, we required subjects to find a target distinguished by the fact that it lacks a feature present in all the distractors. For example, we employed displays consisting of O's and Q's, so that the difference between the target and the distractors is that one is simply a circle whereas the other

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is a circle intersected by a line segment [see illustration on page 120]. We found a remarkable difference in the search time depending on whether the target was the Q and had the line or was the O and lacked the line. When the target had the line, the search time was independent of the number of distractors. Evidently the target popped out of the display. When the target lacked the line, the search time increased linearly with the number of distractors. Evidently the items in the display were being subjected to a serial search.

The result goes against one's intuitions. After all, each case involves the same discrimination between the same two stimuli: O's and Q's. The result is consistent, however, with the idea that a pooled neural signal early in visual processing conveys the presence but not the absence of a distinctive feature. In other words, early vision extracts simple properties, and each type of property triggers activity in popula-

tions of specialized detectors. A target with a unique property is detected in the midst of distractor items simply by a check on whether the relevant detectors are active. Conversely, a target lacking a property that is present in the distractors arouses only slightly less activity than a display consisting exclusively of distractors. We propose, therefore, that early vision sets up a number of what might be called feature maps. They are not necessarily to be equated with the specialized visual areas that are mapped by physiologists, although the correspondence is suggestive.

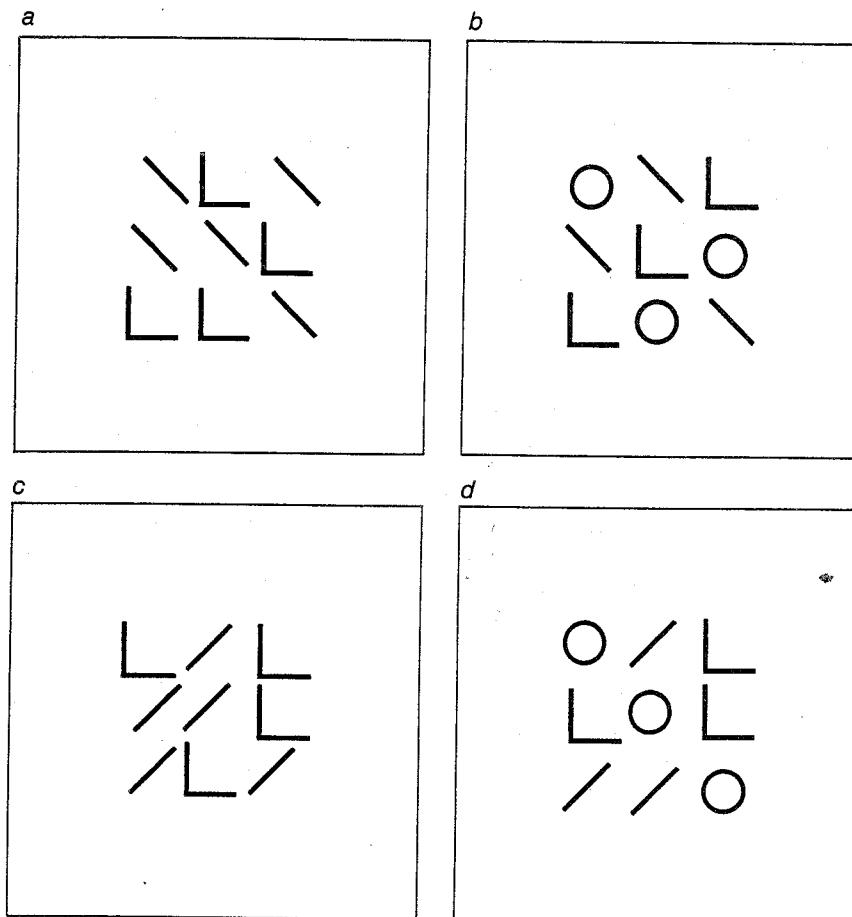
We have exploited visual-search tasks to test a wide range of candidate features we thought might pop out of displays and so reveal themselves as primitives: basic elements in the language of early vision. The candidates fell into a number of categories: quantitative properties such as length or number; properties of single lines such

as orientation or curvature; properties of line arrangements; topological and relational properties such as the connectedness of lines, the presence of the free ends of lines or the ratio of the height to the width of a shape.

Among the quantitative candidates, my colleagues and I found that some targets popped out when their discriminability was great. In particular, the more extreme targets—the longer lines, the darker grays, the pairs of lines (when the distractors were single lines)—were easier to detect. This suggests that the visual system responds positively to "more" in these quantitative properties and that "less" is coded by default. For example, the neural activity signaling line length might increase with increasing length (up to some maximum), so that a longer target is detected against the lower level of background activity produced by short distractors. In contrast, a shorter target, with its concomitant lower rate of firing, is likely to be swamped by the greater activity produced by the longer distractors. Psychophysicists have known for more than a century that the ability to distinguish differences in intensity grows more acute with decreasing background intensity. We suggest that the same phenomenon, which is known as Weber's law, could account for our findings concerning the quantitative features.

Our tests of two simple properties of lines, orientation and curvature, yielded some surprises. In both cases we found pop-out for one target, a tilted line among vertical distractors and a curved line among straight lines, but not for the converse target, a vertical line among tilted distractors and a straight line among curves. These findings suggest that early vision encodes tilt and curvature but not verticality or straightness. That is, the vertical targets and the straight targets appear to lack a feature the distractors possess, as if they represent null values on their respective dimensions. If our interpretation is correct, it implies that in early vision tilt and curvature are represented relationally, as deviations from a standard or norm that itself is not positively signaled.

A similar conclusion emerged for the property of closure. We asked subjects to search for complete circles in the midst of circles with gaps and for circles with gaps among complete circles. Again we found a striking asymmetry, this time suggesting that the gap is preattentively detectable but that closure is not—or rather that it becomes preattentively detectable only when the distractors have very large



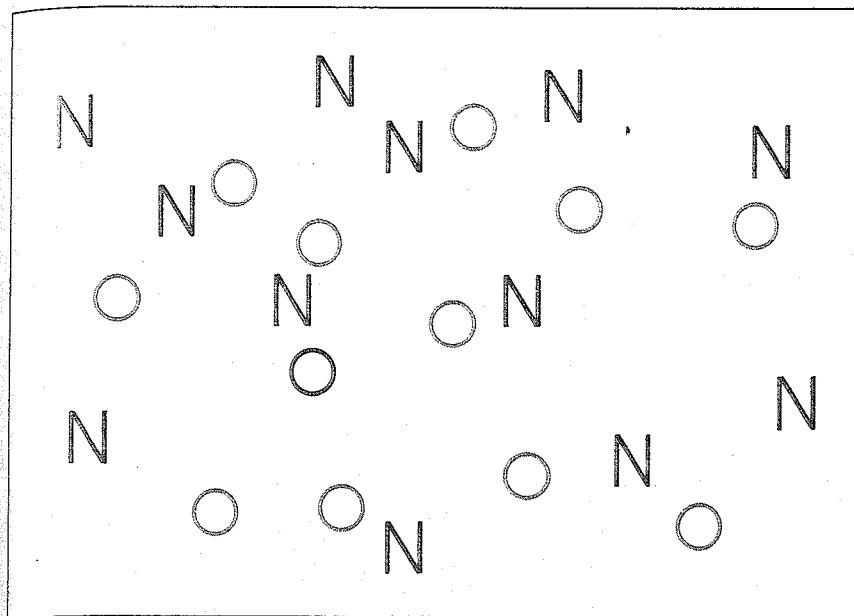
ILLUSORY TRIANGLES constitute a test of what features must be available to support the perception of triangles. Subjects seldom reported seeing a triangle when they were briefly exposed to displays consisting of the line segments that make up a triangle (*a*). They saw triangles far more often when the displays also included closed stimuli, that is, shapes that enclose a space, in this case O's (*b*). Evidently closure is a feature analyzed in early visual processing. This conclusion was supported by showing displays that lack the diagonal line to make a triangle (*c, d*). Subjects seldom saw triangles in such displays.

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SEARCHING A DISPLAY for a target item defined by a conjunction of features proves to take longer the more "distractor" items the display contains. Here the target is a red O; the distractors are green O's and red N's. The target therefore differs from the distractors in its conjunction of shape and color. On trials when no target was present, the average search time increased by some 40 milliseconds for each distractor added to the display. On

trials when a target was present (so that on the average subjects would have to search half of the items before finding the target), the search time increased at about half that rate. The implication is that a target characterized by a conjunction of properties requires subjects who are searching for the target to focus attention on each displayed item in turn. If a target has a unique color or shape, the number of distractors does not influence search time.

gaps (that is, when they are quite open shapes like semicircles). In other words, closure is preattentively detectable, but only when the distractors do not share it to any significant degree. On the other hand, gaps (or the line ends that gaps create) are found equally easily whatever their size (unless they are too small for a subject, employing peripheral vision, to see).

Finally, we found no evidence that any property of line arrangements is preattentively detectable. We tested intersections, junctions, convergent lines and parallel lines. In every case we found that search time increases with an increasing number of distractors. The targets become salient and obvious only when the subject's attention is directed to them; they do not emerge automatically when that attention is disseminated throughout the display.

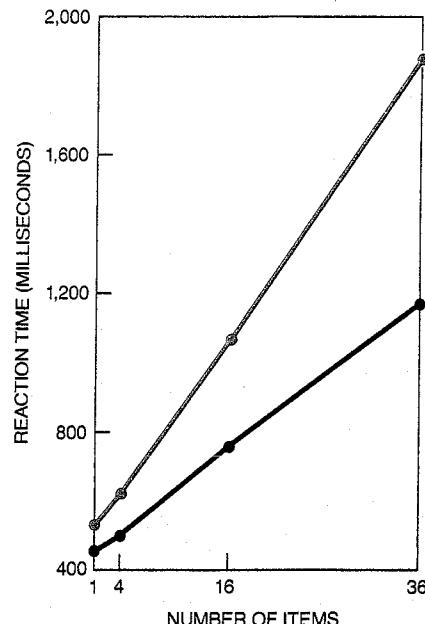
In sum, it seems that only a small number of features are extracted early in visual processing. They include color, size, contrast, tilt, curvature and line ends. Research by other investigators shows that movement and differences in stereoscopic depth are also extracted automatically in early vision. In general the building blocks of vision appear to be simple properties that characterize local elements, such as points or lines, but not the relations among them. Closure appears to be the most complex property that pops

out preattentively. Finally, our findings suggest that several preattentive properties are coded as values of deviation from a null, or reference, value.

Up to this point I have concentrated on the initial, preattentive stages of vision. I turn now to the later stages. In particular I turn to the evidence that focused attention is required for conjoining the features at a given location in a scene and for establishing structured representations of objects and their relations.

One line of evidence suggesting that conjunctions require attention emerges from experiments in which we asked subjects to identify a target in a display and say where it was positioned. In one type of display only a simple feature distinguished the target from the distractors. For example, the target was a red H in the midst of red O's and blue X's or an orange X among red O's and blue X's. In other displays the target differed only in the way its features were conjoined. For example, it was a blue O or a red X among red O's and blue X's.

We were particularly interested in the cases in which a subject identified the target correctly but gave it the wrong location. As we expected, the subjects could sometimes identify a simple target, say a target distinguished merely by its color, but get its location wrong. Conjunction targets



were different: the correct identification was completely dependent on the correct localization. It does indeed seem that attention must be focused on a location in order to combine the features it contains.

In a natural scene, of course, many conjunctions of features are ruled out by prior knowledge. You seldom come across blue bananas or furry eggs. Pre-attentive visual processing might be called "bottom up," in that it happens automatically, without any recourse to such knowledge. Specifically, it happens without recourse to "top down" constraints. One might hypothesize that conjunction illusions in everyday life are prevented when they conflict with top-down expectations. There are many demonstrations that we do use our knowledge of the world to speed up perception and to make it more accurate. For example, Irving Biederman of the State University of New York at Buffalo asked subjects to find a target object such as a bicycle in a photograph of a natural scene or in a jumbled image in which different areas had been randomly interchanged. The subjects did better when the bicycle could be found in a natural context [see illustration on page 115].

In order to explore the role of prior knowledge in the conjoining of properties, Deborah Butler and I did a further study of illusory conjunctions.

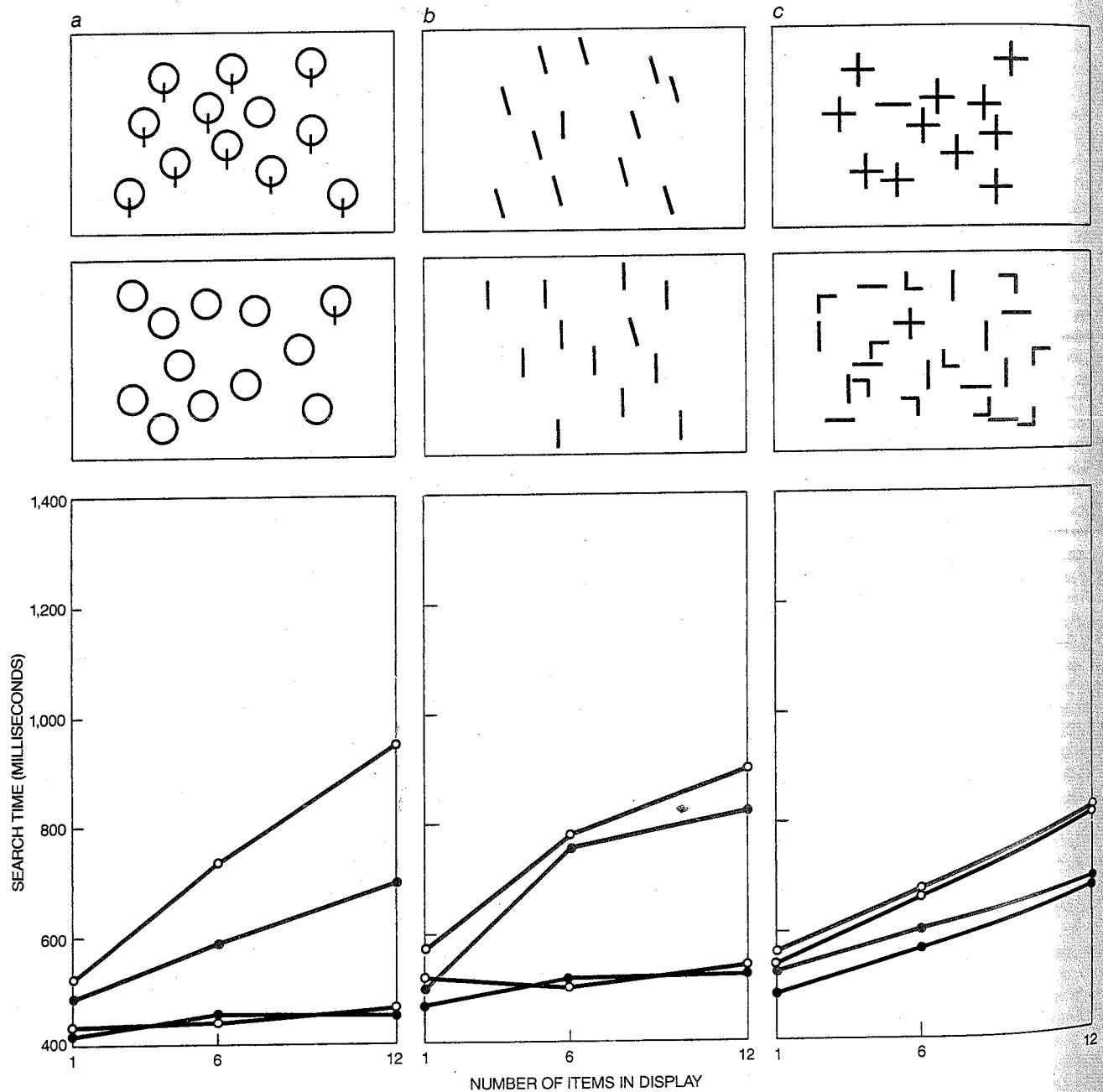
We showed subjects a set of three colored objects flanked on each side by a digit [see top illustration on page 122]. Then, some 200 milliseconds later, we showed them a pointer, which was accompanied by a random checkerboard in order to wipe out any visual persistence from the initial display. We asked the subjects to attend to the two digits and report them, and then to say

which object the pointer had designated. The sequence was too brief to allow the subjects to focus their attention on all three objects.

The crucial aspect of the experiment lay in the labels we gave the objects. We told one group of subjects that the display would consist of "an orange carrot, a blue lake and a black tire." Occasional objects (one in four) were

shown in the wrong color to ensure that the subjects could not just name the color they would know in advance ought to be associated with a given shape. For another group of subjects the same display was described as "an orange triangle, a blue ellipse and a black ring."

The results were significant. The group given arbitrary pairings of col-



PRESSENCE OR ABSENCE of a feature can have remarkably different effects on the time it takes to find a target in the midst of distractors. In one experiment (*a*) the target was a circle intersected by a vertical line segment or a circle without that feature. The search time for the intersected circle (*black*) proved to be largely independent of the number of items in the display, suggest-

ing that the feature popped out. The search time for the plain circle (*color*) increased steeply as distractors were added, suggesting that a serial search of the display was being made. A second experiment (*b*) required subjects to search for a vertical line (*color*) or a tilted line (*black*). The tilted line could be found much faster; evidently only the tilted line popped out of the displays. A

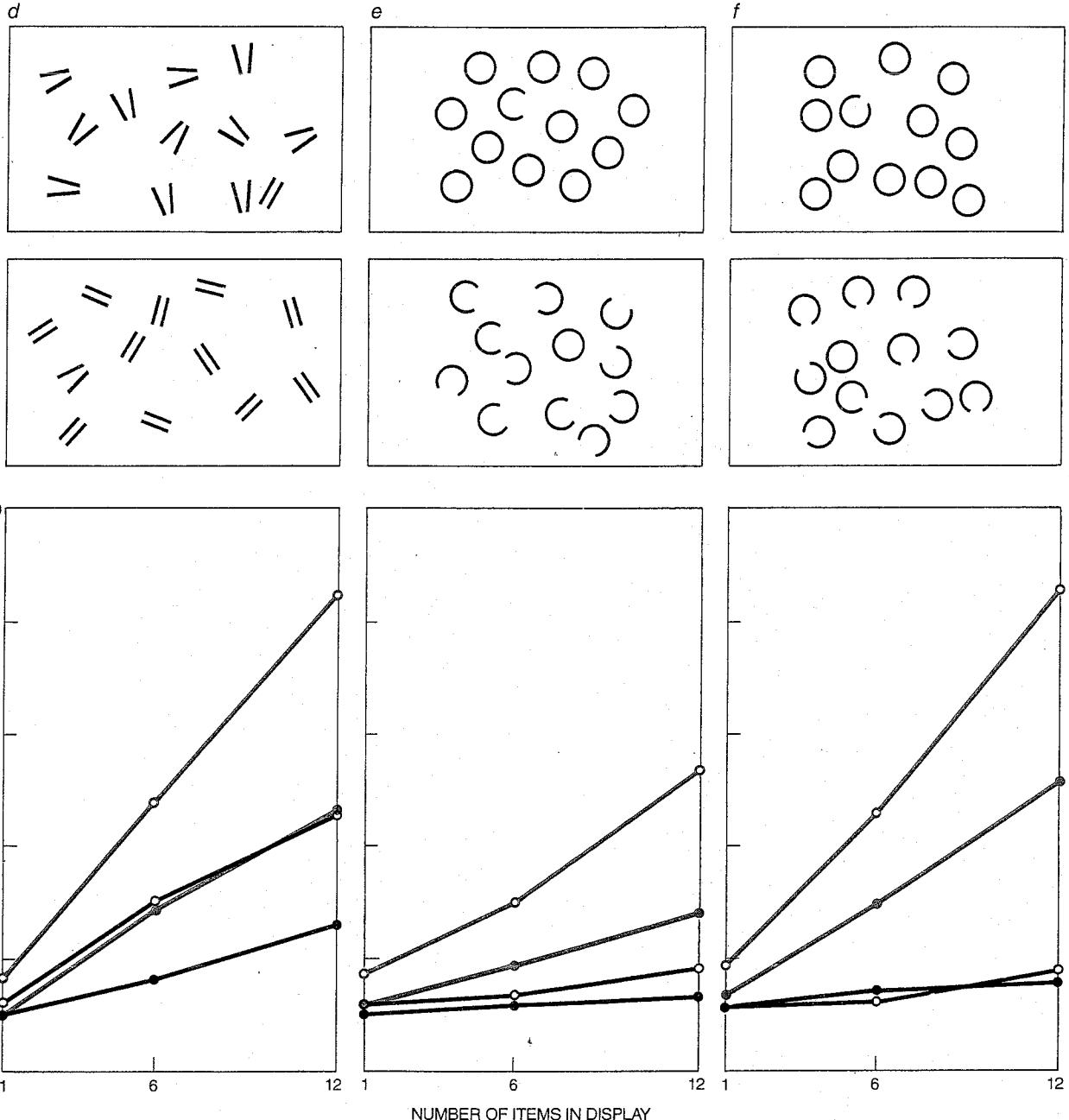
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ors and shapes reported many illusory conjunctions: 29 percent of their responses represented illusory recombinations of colors and shapes from the display, whereas 13 percent were reports of colors or shapes not present in the display. In contrast, the group expecting familiar objects saw rather few illusory conjunctions: they wrongfully recombined colors and shapes only

5 percent more often than they reported colors and shapes not present in the display.

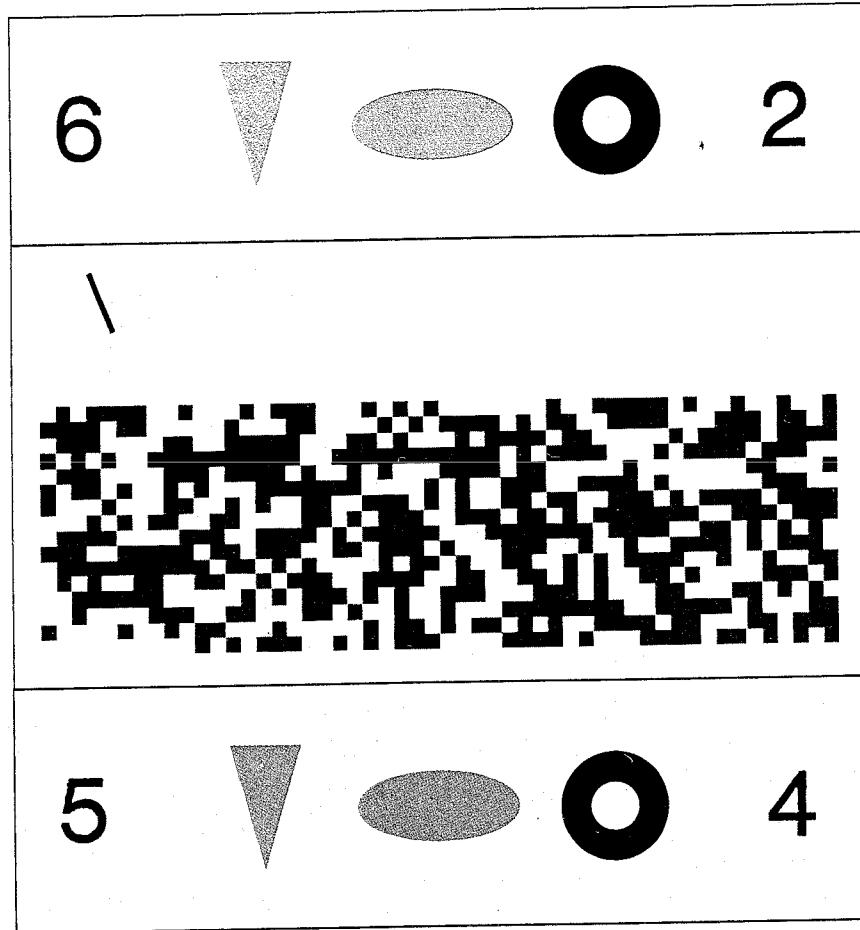
We occasionally gave a third group of subjects the wrong combinations when they were expecting most objects to be in their natural colors. To our surprise we found no evidence that subjects generated illusory conjunctions to fit their expectations. For ex-

ample, they were no more likely to see the triangle (the "carrot") as orange when another object in the display was orange than they were when no orange was present. There seem to be two implications: prior knowledge and expectations do indeed help one to use attention efficiently in conjoining features, but prior knowledge and expectations seem not to induce illusory exchanges

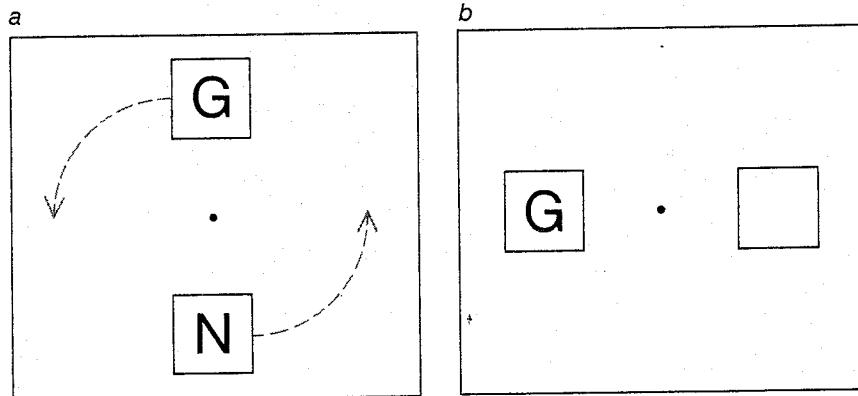


third experiment (c) tested an isolated line segment (color) or intersecting lines in the form of a plus sign (black). Evidently neither popped out. A fourth experiment (d) tested parallel lines (color) or converging lines (black). Again neither popped out. A fifth experiment (e) tested closure with complete circles (color) or circles with a gap of a fourth of their circumference (black). A

sixth experiment (f), again testing closure, had complete circles (color) or circles with smaller gaps (black). The size of the gap seemed to make no difference: the incomplete circle popped out. On the other hand, a complete circle became harder to find as the size of the gaps in distractors was reduced. Open dots represent data from trials in which the display included only distractors.



EFFECT OF EXPECTATIONS on the perception of conjunctions of features turns out to be complex. Subjects were shown three colored shapes flanked on each side by a distractor, specifically a digit (*top*). The display was followed by a masking field and a pointer (*middle*) indicating the prior location of the shape the subject was called on to report. The subjects made many mistakes in associating colors with shapes when they expected arbitrary pairings of colors and shapes (an orange triangle, a blue ellipse and a black ring). Not surprisingly, they made fewer mistakes when they were expecting pictures of familiar objects (a carrot, a lake and a tire). Some displays (*bottom*) showed unexpected combinations when the subjects thought they would see natural ones. Yet the subjects were no more likely to erroneously report, say, an orange carrot if orange was present elsewhere in the display than if orange was absent. These latter trials imply that illusory conjunctions are formed at a stage of processing that is not affected by prior knowledge.



INTEGRATION OF SENSORY INFORMATION into what amounts to a file on each perceptual object was tested by the motion of frames. In each trial two frames appeared; then two letters were briefly flashed in the frames (*a*). The frames moved to new locations, and a letter appeared in one of the two (*b*). The subject's task was to name the final letter as quickly as possible. If the final letter matched the initial letter and appeared in the same frame, the naming was faster than if the letter had appeared in the other frame or differed from the initial letter. The implication is that it takes more time to create or update a file on an object than it does simply to perceive the same object a second time.

of features to make abnormal objects normal again. Thus illusory conjunctions seem to arise at a stage of visual processing that precedes semantic access to knowledge of familiar objects. The conjunctions seem to be generated preattentively from the sensory data, bottom-up, and not to be influenced by top-down constraints.

How are objects perceived once attention has been focused on them and the correct set of properties has been selected from those present in the scene? In particular, how does one generate and maintain an object's perceptual unity even when objects move and change? Imagine a bird perched on a branch, seen from a particular angle and in a particular illumination. Now watch its shape, its size and its color all change as it preens itself, opens its wings and flies away. In spite of these major transformations in virtually all its properties, the bird retains its perceptual integrity: it remains the same single object.

Daniel Kahneman of the University of California at Berkeley and I have suggested that object perception is mediated not only by recognition, or matching to a stored label or description, but also by the construction of a temporary representation that is specific to the object's current appearance and is constantly updated as the object changes. We have drawn an analogy to a file in which all the perceptual information about a particular object is entered, just as the police might open a file on a particular crime, in which they collect all the information about the crime as the information accrues. The perceptual continuity of an object would then depend on its current manifestation being allocated to the same file as its earlier appearances. Such allocation is possible if the object remains stationary or if it changes location within constraints that allow the perceptual system to keep track of which file it should belong to.

In order to test this idea we joined with Brian Gibbs in devising a letter-naming task [*see bottom illustration at left*]. Two letters were briefly flashed in the centers of two frames. The empty frames then moved to new locations. Next another letter appeared in one of the two frames. We devised the display so that the temporal and spatial separations between the priming letter and the final letter were always the same; the only thing that differed was the motion of the frames. The subjects' task was to name the final letter as quickly as possible.

We knew that the prior exposure to a given letter should normally lessen the time it takes to identify the same

AMATEUR ASTRONOMERS and HUBBLE SPACE TELESCOPE

The Hubble Space Telescope Amateur Astronomers Working Group is pleased to announce a program for amateur astronomers to apply for observing time on the Hubble Space Telescope (HST), the most advanced telescope ever built. A limited amount of time is being reserved especially for amateur astronomers on HST by NASA and the Space Telescope Science Institute. Your response could open a new era in amateur astronomy.

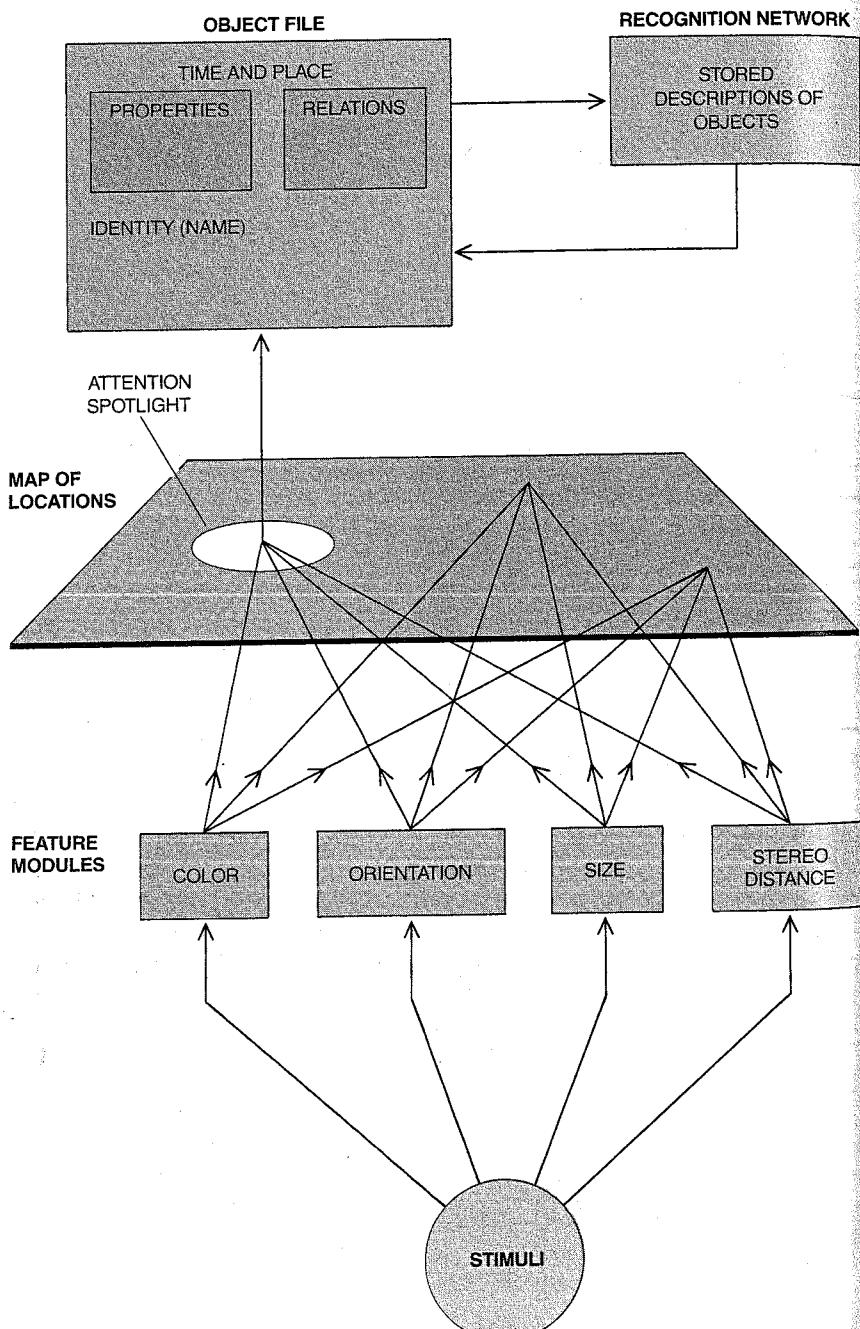
The program is open to readers of SCIENTIFIC AMERICAN who are U.S. citizens, who are not professional astronomers and who have specific projects of scientific or educational value requiring the use of the unique capabilities of HST. With its high sensitivity, extended wavelength range and high resolution, Space Telescope offers many exciting opportunities for astronomical study. Observing time on Space Telescope is so highly sought after that its uses are limited to studies impossible from the ground.

Readers interested in receiving instructions for making preliminary proposals should send \$1 (to cover the cost of materials, postage, and handling) to:

HST Amateur Astronomers Working Group
c/o AAVSO
25 Birch Street
Cambridge, MA 02138

The deadline for completed applications is March 31, 1987. Please make checks payable to the AAVSO.

letter on a subsequent appearance; the effect is known as priming. The question that interested us was whether priming would occur only in particular circumstances. We argued that if the final letter is the same as the priming letter and appears in the same frame as the priming letter, the two should be seen as belonging to the same object; in this case we could think of the perceptual task as simply re-viewing the original object in its shifted position. If, on the other hand, a new letter appears in the same frame, the object file should have to be updated, perhaps increasing the time it takes for subjects to become aware of the letter and name it.



HYPOTHETICAL MODEL of the early stages in visual perception emerges from the author's experiments. The model proposes that early vision encodes some simple and useful properties of a scene in a number of feature maps, which may preserve the spatial relations of the visual world but do not themselves make spatial information available to subsequent processing stages. Instead focused attention (employing a master map of locations) selects and integrates the features present at particular locations. At later stages the integrated information serves to create and update files on perceptual objects. In turn the file contents are compared with descriptions stored in a recognition network. The network incorporates the attributes, behavior, names and significance of familiar objects.

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Actually the priming was found to be object-specific: subjects named the final letter some 30 milliseconds faster if the same letter had appeared previously in the same frame. They showed no such benefit if the same letter had appeared previously in the other frame. The result is consistent with the hypothesis that the later stages of visual perception integrate information from the early, feature-sensitive stages in temporary object-specific representations.

The overall scheme I propose for visual processing can be put in the form of a model [see illustration on opposite page]. The visual system begins by coding a certain number of simple and useful properties in what can be considered a stack of maps. In the brain such maps ordinarily preserve the spatial relations of the visual world itself. Nevertheless, the spatial information they contain may not be directly available to the subsequent stages of visual processing. Instead the presence of each feature may be signaled without a specification of where it is.

In the subsequent stages focused attention acts. In particular, focused attention is taken to operate by means of a master map of locations, in which the presence of discontinuities in intensity or color is registered without specification of what the discontinuities are. Attention makes use of this master map, simultaneously selecting, by means of links to the separate feature maps, all the features that currently are present in a selected location. These are entered into a temporary object representation, or file.

Finally, the model posits that the integrated information about the properties and structural relations in each object file is compared with stored descriptions in a "recognition network." The network specifies the critical attributes of cats, trees, bacon and eggs, one's grandmothers and all the other familiar perceptual objects, allowing access to their names, their likely behavior and their current significance. I assume that conscious awareness depends on the object files and on the information they contain. It depends, in other words, on representations that collect information about particular objects, both from the analyses of sensory features and from the recognition network, and continually update the information. If a significant discontinuity in space or time occurs, the original file on an object may be canceled; it ceases to be a source of perceptual experience. As for the object, it disappears and is replaced by a new object with its own new temporary file, ready to begin a new perceptual history.

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