stimuli rather than the novel, meaningless ones that Rock and Gutman typically studied.

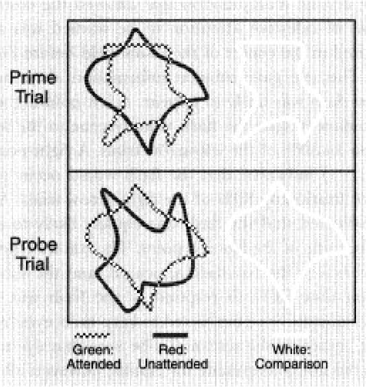

Figure 11.2.8
Negative priming with novel figures. Subjects had to decide whether the green (checkered) and white figures on each trial had the same shape or not. On some sequences of trials, the previous prime trial required subjects to ignore the same figure that had to be attended in the present probe trial. (See text for details.) (After Treisman & DeSchepper, 1996.)

Surprising answers to these and other questions have come from a series of experiments by Treisman and DeSchepper (1996; DeSchepper & Treisman, 1996). To address the third possibility, they looked for negative priming effects using novel figures like Rock and Gut-man's. They did so by changing the task from naming individual figures to deciding whether pairs of figures were the same or different. Each trial's display contained three figures: an attended figure in the target color (green in Figure 11.2.8) overlapping with an unattended figure in the unattended color (red in Figure 11.2.8), and a comparison figure (always white). Subjects had to indicate whether the green and white figures had the same shape or not, and reaction time was measured. The important question was whether the unattended red figure in the "prime" trial would affect performance on a later "probe" trial in which it reappeared as the attended (green) figure.

The critical experimental conditions were defined by the relation between the attended (green) figure on the probe trial and the unattended (red) figure on a previous prime trial after some number of intervening trials. When they were on consecutive trials (lag = 1), a negative priming effect of 55 ms was obtained for trials in which the same shape was repeated (versus control trials in which a different shape preceded it). This result shows that the difference between Rock and Gutman's findings and Tipper's was not due to the novelty/familiarity of the stimulus materials because negative priming was obtained with novel meaningless figures very much like Rock and Gutman's.

Next, DeSchepper and Treisman investigated the effects of delay. Would the negative priming effect last for only a few trials, as Tipper (1985) had found with his familiar shapes, or would it last as long as the memory delays in Rock and Gutman's experiments? Being careful to show each critical figure in only two trials, they found the same amount of negative priming at lags of 1, 100, and 200 trials. Additional experiments showed that measurable effects of a previous exposure could be obtained up to one month later!

These results indicate that the processes underlying negative priming can be very long-lasting indeed if the figures in question are novel. Moreover, they demonstrate how sensitive indirect measures of memory can be. When explicit memory was tested at comparable delays of 72-104 trials using four-alternative forced-choice recognition procedures-that is, picking the one previously shown figure from among four alternatives-memory for unattended shapes was 26%, no higher than chance (25%). Even attended novel figures were recognized only a bit better than chance (34%) at these delays. The primary reason for the difference between the results of Rock and Gutman and those of Tipper and his associates therefore appears to be the use of direct versus indirect measures of visual memory.

11.2.2 Costs and Benefits of Attention

We now turn to the nature of spatial selection under conditions of explicit attention when the observer is expecting the possibility of some event that contains needed information. We have been presuming that if such an event occurs in a location that is attended, it is processed in ways that are somehow different from how it would be if it were not attended. But precisely what are the consequences of explicitly attending to one object or place rather than another?

Selective attention certainly sounds like a good thing if it enables an organism to focus the bulk of its visual processing capacity on objects, locations, and properties of interest. But this concentration of visual resources presumably comes at a price: Unattended objects and/or properties receive correspondingly *less* processing. This is the "double-edged sword" of selective attention: It may have significant costs as well as significant benefits. For it to be evolutionarily useful, the benefits should outweigh the costs.

The Attentional Cuing Paradigm

The question of how to measure the costs and benefits of selective attention has been studied most extensively by psychologist Michael Posner and his colleagues at the University of Oregon. Posner, Nissen, and Ogden (1978) developed an **attentional cuing paradigm** that has proven to be particularly well suited to examining costs and benefits. The task is simplicity itself: Subjects must press a button as soon as they detect a brief flash of light. The light is presented either to the left or to the right of a central fixation point, as shown in Figure 11.2.9.

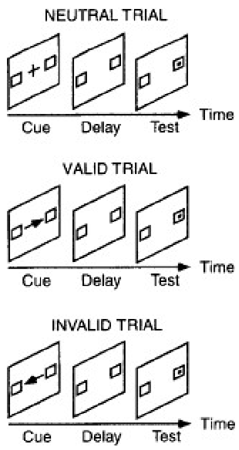

Figure 11.2.9
The attentional cuing paradigm. An arrow pointing toward the left or right box is used to cue subjects to attend there for a target stimulus. On valid trials, the target occurs in the cued location. On invalid trials, it occurs in the uncued location. On neutral trials, the cue is a plus sign.

The crucial manipulation that allowed the costs and benefits of selective attention to be studied was a cue presented in the center of the visual field before the test flash. This cue gave subjects information about where the test flash was likely to appear. A left-pointing arrow (→) indicated that the flash would occur to the right of fixation on 80% of the right-arrow trials. A plus (+) indicated that the flash was equally likely to occur on either side of the fixation point. The cue was shown 1 second before the test flash appeared, and the subject's reaction time (RT) to respond to the flash was measured. Subjects were instructed to keep their eyes fixated on the center of the screen. To be sure that eye movements did not contaminate the results, however, all trials on which subjects moved their eyes were discarded.

The relation between the central cues (→, or +) and the position at which the test flash appeared (on the left or right side of the screen) defines three attentional conditions of interest:

1. *Neutral trials*. When the + cue was presented, subjects got no prior information about the position of the test flash, so they presumably attended equally to both locations. RTs in this divided attention condition constitute a baseline against which RTs in the other two conditions can be compared to evaluate costs and benefits of focused attention.

2. *Valid trials*. On 80% of the arrow-cued trials, the flash appeared on the side to which the arrow pointed. On these "valid" trials, subjects are presumed to move their attention to the location cued by the arrow. If there are measurable benefits of selectively attending to the cued location, detection of the test flash should be faster on these valid trials than on the neutral trials.

3. *Invalid trials*. On 20% of the arrow-cued trials, the flash appeared on the side opposite the arrow, where subjects were *not* expecting it. If there are measurable costs of selectively attending to the cued location, detection of the test flash should be slower on these invalid trials than on both the neutral and the valid trials.

The results of this study are shown in Figure 11.2.10. Posner, Nissen, and Ogden (1978) found that RTs to the valid cues were about 30 ms faster than RTs to the neutral cues and that RTs to the invalid cues were about 30 ms slower. This indicates that both costs and benefits are present in this particular task and that they are about equal. Given that the 30-ms benefit was obtained on 80% of the cued trials (the valid ones) and the 30-ms cost was obtained on only 20% (the invalid ones), the net benefits outweighed the net costs, at least in this objective sense.

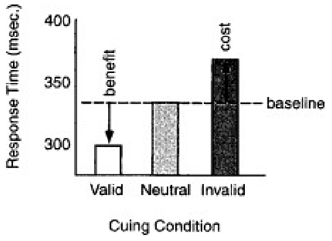

Figure 11.2.10
Costs and benefits of attention. The results in the cuing paradigm show that valid trials are faster than neutral trials (the benefit of correctly directing attention), whereas invalid trials are slower than neutral trials (the cost of misdirecting attention). (Data from Posner, Nissen, & Ogden, 1978.)

Beyond measuring the basic costs and benefits due to attention, Posner and his associates also wanted to measure how long it takes subjects to shift attention to the cued location. They did this by performing a second experiment in which they varied the time interval between the presentation of the arrow cues and the test flashes (Posner, Nissen, & Ogden, 1978). The shortest interval was 50 ms, and the longest was 1000 ms. The experimenters reasoned that if the test flash were presented too soon after the cue, subjects would not have enough time to shift their attention to the cued location, and neither costs nor benefits would result. As the interval between cue and test increases, however, subjects would be increasingly likely to have completed the shift of attention by the time the test flash appeared. Thus, Posner and his colleagues predicted that both costs and benefits would increase as a function of the cue-to-test interval until some maximum level was reached, indicating the completion of the attentional shift.

The results of this experiment are shown in Figure 11.2.11A. Look first at the neutral trials in the middle. RTs to test flashes after the + cues were not much affected by the cue-test interval, presumably because they provided no information about the location of the test flash. This is the baseline to which performance in the other two conditions should be compared. As in the first experiment, performance on valid trials was faster than that on neutral trials. The difference between these two curves therefore measures the benefit of selective attention (Figure 11.2.11B). Notice that the magnitude of this benefit increases steadily as the cue-to-test interval increases, reaching its highest level at about 400 ms. Performance on invalid trials is again slower than that on neutral trials. The difference between these two curves therefore measures the cost of selective attention (Figure 11.2.1lB). Notice that the magnitude of this cost increases as the cue-to-test interval increases, reaching its highest level by 200 ms. Thus, we conclude that attentional shifts from one location to another accrue benefits to the attended location and costs to the unattended location. Moreover, we infer that it takes about 400 ms for people to complete such an attentional shift and that the costs seem to accrue slightly before the benefits.

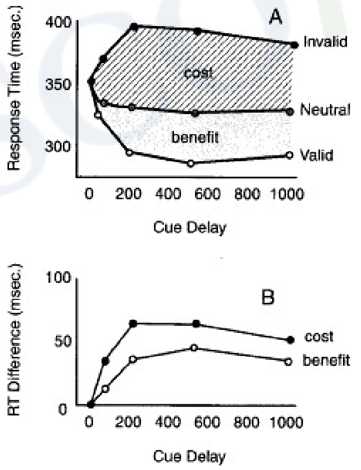

Figure 11.2.11
Temporal development of costs and benefits. Graph A shows the response times for valid, invalid, and neutral conditions as a function of the delay between cue and test displays. Graph B plots the cost (invalid RT minus neutral RT) and benefit (neutral RT minus valid RT) of selective attention. (Part A after Posner, Nissen, & Ogden, 1978.)

Voluntary versus Involuntary Shifts of Attention

Attention researchers have extended this experimental paradigm to study the effects of different kinds of attentional cues. You have probably noticed that when there is a sudden change in your field of view, such as the appearance of a new object, it seems to draw your attention automatically. This involuntary summoning of attention appears to be quite different from the voluntary, effortful process of directing attention according to the arrow cues in the experiments just described.

Jonides (1981) extended the cost/benefit paradigm to find out what kind of differences there might be between voluntary and involuntary shifts of attention. He examined voluntary shifts of attention using centrally presented symbolic cues such as the arrows at fixation as described above. These are sometimes called **push cues** because attention must be "pushed" from the symbolic cue to the cued location. He also examined involuntary shifts of attention by presenting peripheral arrows right next to the cued location. Because it was expected that these peripheral cues could effectively summon attention directly to that location, they are sometimes called **pull cues**. Valid and invalid trials for each cue type were constructed by presenting the target object in the cued location or some other location, respectively.

Several differences have been reported between voluntary and involuntary shifts of attention using push and pull cues:

1. *Pull cues produce benefits without costs*. Push cues produced both benefits and costs relative to the neutral condition. In contrast, pull cues produced benefits without corresponding costs.

2. *Pull cues work faster*. When the cue-to-test interval was varied, the results indicated that an equivalent shift of attention took only about 100 ms instead of 200-400 ms.

3. *Pull cues cannot be ignored*. When the validity of push cues was lowered to chance level (50%), subjects were able to ignore them. When the validity of pull cues was comparably reduced, they still produced significant benefits. Indeed, they did so even when subjects were instructed to actively ignore them.

Three Components of Shifting Attention

The re-suits of these experiments on attentional cuing clearly demonstrate that attention has measurable effects on a task as simple as detecting the onset of a visual signal. They also show that it can be moved under either voluntary or involuntary control. Moving attention from one object to another seems intuitively simple enough, but how exactly does it happen?

Posner has suggested that a sequence of three component operations is required to shift attention from one object to another (e.g., Posner & Petersen, 1990; Posner, Walker, Friedrich, & Rafal, 1984):

1. *Disengagement*. Since attention is normally focused on some object, the first thing that must happen is to disengage it from that object.

2. *Movement*. Once it is disengaged, attention is free to move and must be directed toward the new object.

3. *Engagement*. After reaching the target, attention must be reengaged on the new object.

Moving attention from one object to another seems so simple that it is hard to believe that it is composed of these separate processes. However, evidence from neuropsychology suggests not only that they are distinct operations, but that they are controlled by three widely separated brain centers.

Patients with damage to parietal cortex (see Figure 11.2.12) show a pattern of costs and benefits on the cuing task, indicating that they have difficulty *disengaging* their attention from objects. Patients with damage to the superior colliculus in the midbrain show a different pattern of results, suggesting that they have difficulty *moving* their attention. (These patients are also severely impaired in making voluntary eye movements, a fact that suggests an important connection between attention and eye movements to which we will return at the end of this chapter.) Finally, patients with damage to certain centers in the thalamus, including the lateral pulvinar nucleus, appear to have difficulty *engaging* their attention on a new object. Thus, the seemingly simple and unitary operation of shifting attention from one object to another actually requires a coordinated effort among three widely separated regions of the brain. When neural functioning in these areas is impaired, attentional movements fail in predictable ways (see Posner & Raichle, 1994, for a review).

11.2.3 Theories of Spatial Attention

How can we understand visual attention theoretically? As is often the case in cognitive science, the first step in theorizing about a mental process is to find an appropriate metaphor. Because attention is a rather mysterious, unobservable entity, theorists have tried to understand it in terms of physical systems they can observe directly and therefore understand better. We have already encountered one such metaphor: Attention is like an internal eye. The internal eye metaphor captures some important facts about attention. Two of these facts are that it appears to move from object to object and that it has a fovealike center where processing is concentrated.

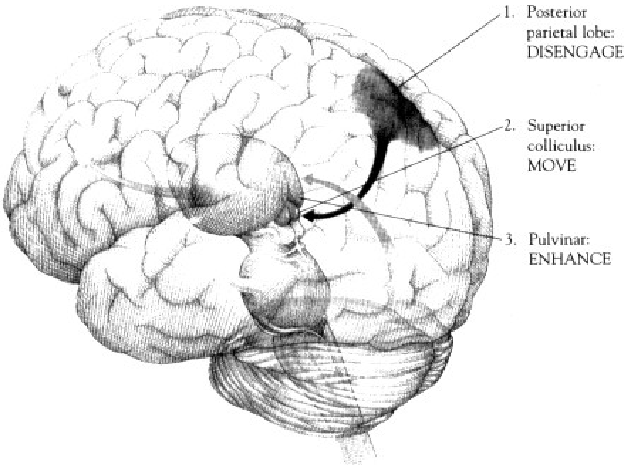

Figure 11.2.12
Three brain centers that are involved in orienting attention. Areas of parietal cortex control the disengagement of attention from objects; circuitry in the superior colliculus in the midbrain controls the movement of attention from one location to another; and certain centers in the thalamus, including the lateral pulvinar nucleus, control the engagement of attention on a new object. (From Posner & Raichle, 1994.)

The internal eye metaphor is of limited theoretical utility, however, because there is a sense in which it is the operation of the eyes (i.e., vision) that we are trying to explain in the first place. The eye metaphor therefore has the potential problem of infinite regress: If attention is like an internal eye and if the real eye has an internal eye of attention, then does the internal attentional eye also have its own internal eye? And what about the internal eye of that internal eye? Even if the answers to these questions are negative-there may be just one internal eye of attention-many theorists find it preferable to liken attention to something simpler and better understood than an eye.

The Spotlight Metaphor

Among the most crucial aspects of the internal eye metaphor are the selection of one region on which to concentrate processing and the ability to move from one region to another over time. A simpler metaphor that captures both of these characteristics is that attention is like a spotlight (e.g., Posner, 1978). According to this **spotlight theory**, the object at the location where the spotlight of attention is focused is "illuminated" so that it stands out and can be processed more effectively than the less illuminated objects in other regions. Once that object has been processed, the attentional spotlight can be shifted to a different location by moving along a path from the present object to the next one, presumably through the disengage/move/ engage sequence of elementary attentional operations mentioned earlier.

The spotlight metaphor of attention has proved both popular and productive. Many experimental results can be understood in terms of it, and new experiments have been devised to test some of its predictions. Consider how Posner's cuing results might be explained, for example. On a cued trial, subjects use the cue to move the attentional spotlight from the central cue to the appropriate location. If the test flash occurs there (a valid trial), it is already in the spotlight of attention, so it can be processed quickly without requiring any subsequent attentional shift. However, if the test flash occurs on the unexpected side (an invalid trial), the spotlight is in the wrong location and must be moved to the correct one before the response can be made. If there is no directional cue (a neutral trial), the spotlight stays in the center and would be moved only half as far as it would on an invalid trial. The spotlight metaphor can thus account for the basic pattern of results shown in Figure 11.2.10. It can also account for the results obtained when the cue-to-test interval is varied, because it will take some amount of time for the attentional spotlight to reach the cued side from the center.

Further experiments have tested a number of predictions derived from the spotlight metaphor. Some have received strong support, but others are controversial. Among the most interesting predictions are the following:

1. *Rate of motion*. The amount of time it takes to shift attention to a target object should increase systematically with the distance over which it must be moved, as though a spotlight were scanning from one place to another. Tsal (1983) has obtained evidence supporting this prediction and has estimated the rate of motion experimentally at about 8 ms per degree of visual angle.

2. *Trajectory*. When a spotlight is moved from one object to another, it illuminates the objects along the path between them. Some evidence suggests that the same is true when attention is moved (e.g., Shulman, Remington, & McLean, 1979).

3. *Size*. Spotlights are generally fixed in size. Eriksen and Eriksen (1974) reported evidence suggesting that the attentional spotlight is about 1 degree of visual angle in size. (As we will see, however, there is also evidence that it can vary in size.)

4. *Unitariness*. A spotlight can be moved from place to place, but it cannot be divided into two or more separate regions. Eriksen and Yeh (1985) reported evidence suggesting that the same is true of attention. (But again there is also evidence for the opposite conclusion.)

Despite its successes, there are a number of problems with the simple spotlight metaphor that have led theorists to consider alternatives. One difficulty is that, despite Eriksen and Eriksen's (1974) conclusion that attention covers only about 1 degree of visual angle in their particular experiment, it seems that under normal viewing conditions attention can cover a much wider area of the visual field, such as when you look globally at a large object or even a whole scene. It also seems that attention can be narrowed to a tiny region of the visual field, as when you scrutinize a small detail. These considerations have led to an alternative metaphor.

The Zoom Lens Metaphor

The **zoom lens theory** likens attention to the operation of a zoom lens on a camera that has variable spatial scope (Eriksen & St. James, 1986). The analogy is not exact, however, for the idea is that attention can cover a variable area of the visual field is usually coupled with the further assumption that varying the size of the attended region changes the amount of visual detail available within it. With a relatively wide attentional scope, only coarse spatial resolution is thought to be possible, whereas with relatively narrow scope, fine resolution is possible.

Shulman and Wilson (1987) tested this idea experimentally. They showed subjects large letters made up of small letters, like the stimuli Navon (1977) used to study global and local processing (see Section 7.6.3), as illustrated in Figure 7.6.9. On some trials, subjects had to identify the large letters, and on other trials the small ones. Shortly after each such trial, they had to respond to a sinusoidal grating that was either low in spatial frequency (wide fuzzy stripes) or high in spatial frequency (thin fuzzy stripes) (see Section 4.2.1). Shulman and Wilson found that responses to low-spatial-frequency gratings were enhanced after subjects had attended to the large global letter and that responses to high-spatial-frequency gratings were enhanced after subjects had attended to the small local letters. This is precisely what would be expected if attention worked like a zoom lens that took time to be adjusted to different sizes and spatial resolutions, large sizes being associated with coarse resolution (low spatial frequencies) and small sizes with fine resolution (high spatial frequencies). These findings are therefore widely cited as supporting the zoom lens metaphor.

Notice that the spotlight metaphor is actually compatible with the zoom lens metaphor in the sense that they can be usefully combined. One can easily conceive of a spotlight that is variable in size as well as position. If the total power of the spotlight is fixed, then a wide beam will illuminate a large region dimly, and a narrow beam will illuminate a small region intensely. This connection between beam width and brightness is not exactly the same as the presumed relation between attentional scope and resolution, but it provides a relatively simple metaphor for thinking about how attention might be distributed over space in a way that includes position, scope, and effectiveness.

Space-Based versus Object-Based Approaches

The metaphors for attention that we have considered thus far-an internal eye, a spotlight, and a zoom lens-all have one important thing in common: They assume that attention selects a region of space. A spotlight, for example, illuminates whatever lies within its beam, whether it is an object, part of an object, parts of two or more nearby objects, or nothing at all. An important alternative to these **space-based theories** is the possibility that attention actually selects a perceptual object (or group of objects) rather than a region of space (e.g., Duncan, 1984). Notice that these **object-based theories** of attention allow a good deal of leeway in how attention might be deployed, because of differences in what constitutes a perceptual object. It could be directed at a single complete object, part of an object, or even an aggregation of objects, as discussed in Chapter 6 when we considered the hierarchical structure of perceptual organization.

Identifying perceptual objects as the domain of selective attention might make object-based accounts seem too ill-defined to be useful, but it does impose significant constraints on the distribution of attention. Unlike space-based theories, for example, object-based theories of attention cannot account for selection of arbitrary portions of two or more different objects, even if they are located within a spatially circumscribed region such as might be illuminated by a spotlight. Also unlike space-based theories, object-based theories can, under certain conditions, account for attentional selection of several discontinuous regions of space. These conditions require that the "object" of attention be a perceptual grouping of several objects whose members are typically defined by some common property (such as color or motion) with other objects interspersed between them. If attention can be allocated just to the set of objects within such a group, it need not occupy a connected region of space. The spotlight and zoom lens metaphors require that a unified region of space be selected.

Some of the strongest evidence for an object-based view of attention comes from a neurological condition known as Balint's syndrome, in which patients are unable to perceive more than one object at any time. We will discuss this syndrome later (in Section 11.2.7) when we consider the physiology of attention, but there is also good experimental evidence for object-based attention with normal perceivers. One of the most widely cited studies is an experiment by Duncan (1984). He reasoned that if attention is allocated to objects rather than to regions of space, it should be easier for subjects to detect two different properties of the same object than two properties of different objects that lie within the same region of space. He showed subjects displays like the one illustrated in Figure 11.2.13. Each stimulus consisted of two objects: a box with a gap in one side and a line running through the box. Each object had two relevant attributes. The box was either short or long and had the gap slightly to the left or right of center. The line was either dotted or dashed and tilted clockwise or counterclockwise from horizontal. After a brief presentation, subjects had to report either one or two attributes. When two attributes were tested, they could belong to the same object or different objects. Duncan found that if the two attributes belonged to different objects, subjects were worse at detecting the second property than

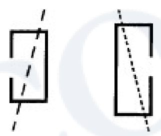

Figure 11.2.13
Stimuli for Duncan's experiment on object-based attention. Subjects had to report two features of a stimulus display that varied on four dimensions: line slant (left or right), line type (dashed or dotted), box length (long or short), and gap placement (left or right). Performance was better when the two features belonged to the same object than to different objects.

the first. But if they belonged to the same object, no such difference was obtained.

These results can easily be explained within an object-based view of attention. When the two properties come from the same object, no shift of attention is required because attention is defined by the single object. When they come from different objects, an attentional shift is required to detect the second property, taking additional time and therefore reducing accuracy. This pattern of results is more difficult to square with space-based theories, however, because the two objects occupy essentially the same region of space. A roughly circular spotlight that illuminates either the box or the line, for instance, will necessarily illuminate the other object. It is therefore not clear how such a difference in detecting properties would arise unless objects were somehow implicated in the allocation of attention. Notice that if a space-based theory allows the attentional spotlight to be shaped tightly around specific objects (e.g., LaBerge & Brown, 1989), they take on a significantly object-based flavor.

There is also recent evidence from a Posner-type cuing experiment suggesting that attention operates at an object-based level. Egly, Driver, and Rafal (1994) showed subjects displays containing two rectangles oriented either horizontally or vertically, as shown in Figure 11.2.14. After the initial presentation, the edges of one end of one rectangle brightened briefly, providing a pull cue to attend to that location. Subjects were then to make a response as quickly as possible when a dark square appeared anywhere in the display. When the cue was valid, the target square appeared briefly in the cued end of the cued object. There were two different types of invalid cues trials, however. In the *same object condition*, the target square appeared in the opposite end of the cued rectangle. In the *different object condition*, it appeared in the uncued object but at the same end as tile cue.

As usual in the cuing paradigm, responses were faster when the target appeared at the cued location than when it appeared at either of the uncued locations. The results for the uncued locations showed object-based attentional effects, however, in that the same object condition was faster than the different object condition, even though their distances from the cued location were equal. This finding suggests that switching from one object to another incurs an additional cost that cannot be attributed to distance.[3]

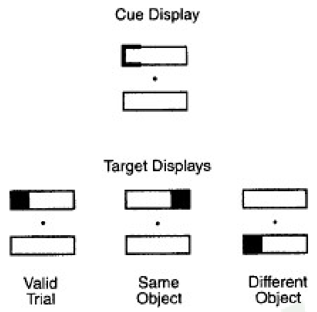

Figure 11.2.14
Stimuli for an experiment showing both space-and object-based attention. One end of two rectangular boxes was cued before presentation of the target in one of three locations. Same-object responses were faster than different-object responses, indicating an object-based attentional effect.

A third finding that lends credence to the object-based view concerns an observer's ability to keep track of several moving objects at once. Pylyshyn and Storm (1988) showed subjects a random array of static dots and designated several of them as target objects to be attended by flashing them on and off. All the dots then began to move in quasi-random (but continuous) trajectories, and subjects were instructed to try to keep track of the ones that were initially designated as targets. After several seconds of such motion, one of the elements flashed, and subjects were asked whether or not that particular dot was one of the initially designated targets. Pylyshyn and Storm found that subjects could track as many as five dots at once.

If one believes that this tracking task requires attention (and Pylyshyn and Storm do not), these results pose significant problems for space-based theories of attention. First, most space-based theories assume that the region to which attention can be allocated is a unitary,

[3] More recent experiments have shown that the "objects" in question are perceptually completed objects rather than retinally defined objects. Moore, Yantis, and Vaughan (1998) concluded this after finding results similar to those of Egly, Driver, and Rafal when the different ends of the same-object stimuli had been retinally separated by an occluding object. They also found this pattern of results when the two ends of the same object were defined only by illusory contours.

convex, connected area. However, the tracking task seems to require observers to attend to a number of disconnected spatial regions at the same time. Equally important, the trajectories of regions through space are defined only by virtue of the objects that traverse them. How else could attention be allocated to the proper regions of space at the proper times?

These results have another feature that is at least somewhat troubling from the object-based perspective, however: They seem to indicate that attention can be split among multiple objects. One could, of course, extend the object-based view specifically to allow Indeed, this is how Pylyshyn and Storm (1988) interpreted their results. But there is another possibility that does not require giving up the unitary nature of attention. Perhaps observers keep track of the multiple dots by grouping them initially into a single super-ordinate object and attending to that group as a unitary entity. The designated dots could then be perceived, for example, as the corners of a virtual polygon whose shape changes over time as the dots move. Yantis (1992) has tested predictions from this hypothesis and found support for them in several experiments.

The current debate between object-based and space-based theories of attention often implies that they are mutually exclusive-that one or the other is correct but not both. This would presumably be the case if attention operates at just one level in the visual system. But what if attention operates at multiple levels? At an early image-processing level, such as Marr's primal sketch, a space-based definition of attention is the only thing that makes much sense, because in this low-level representation, coherent "perceptual objects" have not yet been designated. But at a higher level, after organizational processes have identified figures against grounds, objects could certainly be the basis for allocating attention. Both hypotheses may therefore be correct, just at different levels of the visual system.

11.2.4 Selective Attention to Properties

The theories of selective attention we have just discussed-including spotlights, zoom lenses, and even object-based theories-are designed to account for spatial selection. They cannot be the whole story of visual attention if its capabilities extend to selection of different properties, however. When you inspect a prospective purchase at a clothing store, for example, you seem to be able to focus selectively on its color, style (shape), texture, and size as you consider the garment. This ability appears to imply that attention must have important nonspatial components that select for other sorts of properties. Such evidence is anecdotal at best, however. Can people really attend to different properties of the same object independently or does attending to one necessarily result in perceiving them all? In this section we will consider experimental evidence that bears on this question.

The Stroop Effect

Early experiments seemed to indicate that if an object is attended, certain properties are processed automatically, even if the observer is trying to ignore them. This implies that selection by properties is either nonexistent or incomplete.

The best-known evidence for this conclusion comes from the **Stroop effect**, named for the psychologist, J. Ridley Stroop, who discovered it in 1935. The Stroop effect refers to the fact that when subjects are required to name the color of ink in which color words are printed, they show massive interference when the color word itself conflicts with the ink color to be named (Stroop, 1935). Examples of stimuli that produce this effect are shown in Color Plate 11.1.

You can demonstrate the Stroop effect for yourself by timing how long it takes you to name the ink colors in the column of X's on the left (the control condition) versus the conflicting color-word condition in the center versus the compatible color-word condition on the right. Even without timing yourself with a stopwatch, you will find it much more difficult to get through the middle column than the other two. This fact indicates that shape information is being processed automatically whenever the color of the word is attended and that the response to the identity of the word interferes with naming the ink color. This finding seems to imply that, unlike our intuitions based on everyday experience, selective attention to color, independent of shape, may not be possible after all.

One might wonder whether this interference is specific to color. Further research has shown that it is not. Stroop interference occurs, for instance, if the subject's task is to name an object that is drawn in outline around the name of a different object, as illustrated in Figure 11.2.15A. It also occurs when subjects have to name the location of letter strings (LEFT, RIGHT, or XXXX) when they are presented on either the left or right side of the display, as shown in Figure 11.2.15B (Clark & Brownell, 1975, 1976).

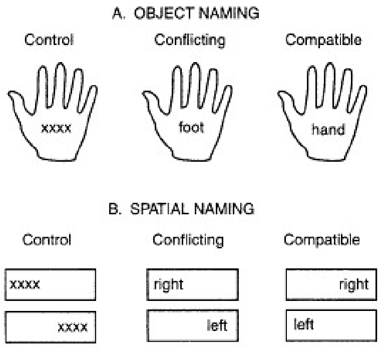

Figure 11.2.15
Additional Stroop effects. Stroop compatibility effects are also found in naming drawings of objects when object names are presented inside them (A) and in naming spatial locations when location names are the objects to be located (B).

Interestingly, interference in the reverse direction does not occur in the standard Stroop task: Color words can be read just as quickly when they are printed in a conflicting color of ink as when they are printed in the compatible color. This shows that some selective attention to properties is indeed possible. It also suggests that there may be something special about reading printed words. One important consideration is that reading is a salient and highly practiced perceptual task. Educated people spend a significant portion of their waking hours reading printed words, and this degree of practice may result in highly automatic processing of letters and words. Another relevant factor is that there is a much more direct association between the printed color word and the sound of the color name (which is what the subject must produce) than there is between the color itself and the sound of the color name. That is, the letter-to-sound correspondences of English may provide more direct access to the name than the color does. The importance of this fact is supported by the finding that Stroop interference is reduced significantly when subjects must press different buttons to indicate ink color rather than when they must say color names. It also explains why noncolor words that begin with the same letters as color words also produce Stroop interference, such as ROD instead of RED or BLOB instead to BLUE. (See MacLeod, 1991, for a review of Stroop effects.) These factors suggest that we should consider evidence from other kinds of tasks that do not depend so heavily on the special properties of reading printed words before we draw conclusions from what may be a very special case.

Integral versus Separable Dimensions

Psychologist Wendell Garner of Yale University has also attempted to answer questions about selective attention to different properties, including both discrete features and continuous dimensions. From an extensive series of experiments, he concluded that there is no single, simple answer. Different patterns of results arise, depending on the particular pair of dimensions being studied. His findings led him to distinguish between two different relations that can hold between pairs of properties or dimensions: *separability* and *integrality* (Garner, 1974).

1. *Separable dimensions*. Pairs of dimensions are **separable** if people can selectively attend to one or the other at will, without interference from the unattended property. The internal representations of separable dimensions therefore appear to be completely independent. Classic examples of separable dimensions are the color and shape of an object, both of which Garner found could be perceived selectively.

2. *Integral dimensions*. Pairs of dimensions are **integral** if people cannot selectively attend to one without also perceiving the other. Classic examples of integral dimensions are the saturation and lightness of a color. These two dimensions seem to be processed together whenever one attends to the color of an object.

The integral/separable dichotomy arose in a number of different experimental paradigms that Garner developed. The most powerful and widely studied method concerned a set of closely related tasks requiring speeded classification. Subjects were presented with various subsets of four stimuli defined by two different dimensions and were asked to classify them in different ways on different tasks. The speed of the perceptual discrimination was measured by reaction time. We will illustrate these conditions using the example of figures defined by their lightness and shape, as depicted in Figure 11.2.16. Each gray rectangle represents a block of many trials in which subjects had to classify the individual stimuli within it into two classes according to the rule implied by the dashed line. For example, in the first two blocks of trials the task might be to classify individual stimuli according to lightness alone, as indicated in the first row of stimuli in Figure 11.2.16. In this case, subjects would have to press one button for white figures and another for black figures. In later blocks of trials, the task would be to classify according to shape alone, as indicated in the second row of stimuli in Figure 11.2.16. In this case, they would have to press one button for squares and another for circles. Other blocks of trials would require the other discriminations indicated in the other rows of Figure 11.2.16.

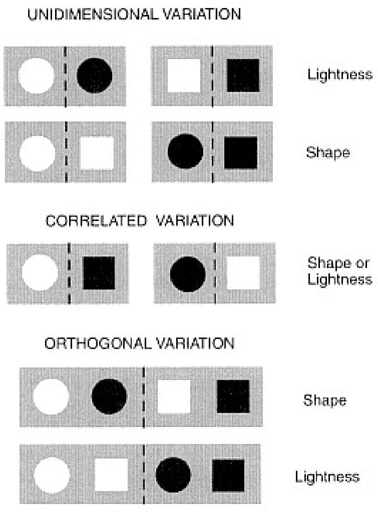

Figure 11.2.16
Three speeded classification tasks studied by Garner. Subjects were required to discriminate between two values of one dimension when the other dimension was held constant (variation), when the other dimension co-varied (correlated variation), or when the other dimension varied independently (orthogonal variation).

There are three critical conditions for determining whether the two given dimensions are integral or separable. These conditions are defined in terms of how the unattended property varies with respect to the attended one within different blocks of trials, as illustrated in Figure 11.2.16.

1. **Unidimensional variation condition**. Subjects are told to classify the stimuli according to their value on one of the two dimensions while the other dimension is held constant.

On a unidimensional block of trials subjects would classify white squares and black squares according to lightness; on another block of trials they would classify white circles and black circles according to lightness. Thus, the shape of the figures is constant within each block of trials in which lightness is the dimension of classification. The same procedure would be followed for the other dimension on further blocks of trials-for example, white squares and white circles would be classified by shape in one block, and black squares and black circles by shape in another block. Note that in these unidimensional variation conditions, only two of the four stimuli are presented in any given block.

2. **Correlated variation condition**. Subjects again are told to classify the stimuli according to the value on just one dimension, but the other dimension varies in a correlated fashion.

For instance, white squares would be discriminated against black circles in one block of trials. In another block, black squares would be discriminated against white circles. In the correlated condition, therefore, subjects could use either of the two properties-or both simultaneously-to perform the classification task. If performance in these correlated conditions is faster than in either of the two unidimensional conditions, the difference in reaction time is called a **redundancy gain** because the two properties in the correlated condition are redundant with each other. As in the unidimensional case, only two of the four stimuli are presented in any one block.

3. **Orthogonal variation condition**. Subjects again have to classify according to a single specified dimension, but this time the other dimension varies independently (orthogonally) so that all four stimuli are presented within each block of trials.

On one block of trials subjects would have to classify all four stimuli according to shape alone (square versus circle), and in another block according to lightness alone (black versus white). In these orthogonal conditions, subjects have to actively ignore the second dimension to perform accurately. It therefore might take additional time to effectively separate the relevant dimension from the irrelevant one. If performance in these orthogonal conditions is slower than for the corresponding unidimensional case, the difference in reaction time is called an **interference loss**.

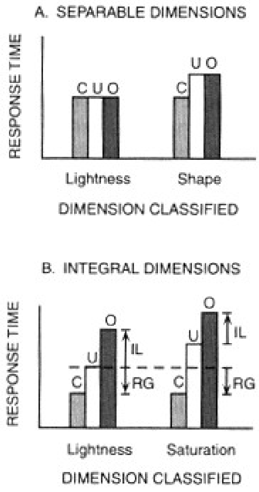

Figure 11.2.17
Characteristic patterns of results for separable versus integral dimensions.
(C = correlated, U = unidimensional, O = orthogonal, IL = interference loss,
RG = redundancy gain; see * text for details.)

Figure 11.2.17A shows idealized results that might be found for these three conditions. Reaction times in the unidimensional conditions (U) give the baseline data for each dimension and show that discriminating shape takes longer than discriminating lightness. Comparing these times to those of the correlated conditions (C) shows no significant differences from the faster unidimensional case (in this case, lightness), indicating that there is no redundancy gain when either or both properties could be used to make the discrimination. The results of the orthogonal condition also show no significant difference from the corresponding unidimensional case, indicating no interference loss. This is the pattern of results expected for separable dimensions, assuming they can be selectively attended at will: neither redundancy gain nor interference loss. Such results therefore support the view that selective attention to properties is possible.

When the stimuli are single color chips that vary in saturation and lightness, however, the pattern of results changes dramatically to that characteristic of integral dimensions. As shown in Figure 11.2.17B, the correlated (C) condition produces a significant redundancy gain (RG) compared to the unidimensional (U) condition in both cases. The orthogonal (O) condition also produces a significant interference loss (IL) relative to the corresponding unidimensional (U) condition in both cases. It is as though subjects cannot pay attention to either one of the properties without automatically perceiving the other. If the two properties vary together, they help performance; if they vary independently, they hurt performance. Quite a different pattern of results emerges, however, if the same two dimensions of color are used in two spatially separated color chips. There is now no redundancy gain and no interference loss (that is, the same pattern as in Figure 11.2.17A). Thus, when lightness and saturation are spatially separated, they are attentionally separable. This fact reflects the efficiency of spatial selection.

Garner developed several other tasks using pairs of properties whose results he expected to support the distinction between separable and integral dimensions. One such task was to have subjects make a particular kind of similarity judgment. On each trial they were presented with three stimuli and asked to indicate which two seemed most similar. The three stimuli differed on two dimensions, as shown in Figure 11.2.18. The question was which pair subjects would see as most similar: Y and Z, which were closer together in the two-dimensional space of stimulus attributes but differed on both dimensions, or X and Y, which had exactly the same value on one dimension but were farther apart in the stimulus space. The results of many experiments showed that subjects tend to choose the "close" pair (Y and Z) as being most similar when the two dimensions were found to be integral in the speeded classification tasks described above. This situation is illustrated in Figure 11.2.18B by the dimensions of a rectangle's width and height. Most people see Y as being more similar to Z than to X in this example. In contrast, people tend to