Getting the Picture

How does the brain build a comprehensible picture of the visible world? Research over recent decades has taught us that the brain does not, in fact, process a given scene as a whole. Instead, parts of the brain work independently and in parallel to process information about various aspects of each figure—location, form, color and movement. If we watch, say, a camel trot in front of a palm tree in a desert, we perceive the camel’s swaying motion and dusty hue separate from its humped form. How does the brain link such features into a complete picture is not well understood and is dreaded by scientists as the “binding problem.” How does a feature bind to “its” object? Why don’t we experience erroneous bindings more frequently?

Our group at the University of Bremen in Germany is systematically exploring such questions in a series of experiments. By showing subjects small visual inputs for barely detectable fractions of a second, we stress the visual system so that it reveals some of its secrets.

Inheriting a Feature

In our initial experiment, observers focused their attention on a monitor. We first presented two slightly staggered vertical bars—a so-called vernier—for 30 milliseconds. Immediately afterward a grating made up of five parallel double bars appeared for 300 milliseconds. The subjects reported that they could see only the grating. Remarkably, the grating was now offset, having inherited that characteristic from the subconsciously perceived vernier. From this test, we now know that the feature of being staggered is processed independently of the vernier and then falsely bound to the outer bars of the grating, where the study participant concentrates his or her attention. Features can thus live their own lives for a short time.

Simple changes in the grating can influence binding. When the grating has 25, instead of five, double bars, the image changes dramatically: one consciously sees the vernier superimposed on the grating. This illusion is called a shine-through element. The feature of being staggered is now correctly bound to the vernier (not to the grating), and the observer sees them as two separate items.

Which mechanisms influence which features bind to which objects? Clues may come from the ways in which the brain “segments” a scene into several discrete entities. In this manner, the brain puts the emphasis on the camel in the desert as a distinct item and interprets the animal as being different from the palm tree. To further investigate the phenomenon of segmenting, we removed two elements from the 25-bar grating. We found that the shine-through effect disappeared. The vernier was invisible, and the observers instead perceived three smaller gratings—that is, three independent objects became segmented. The middle grating again was askew.

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A Possible Mechanism

We propose a model that describes how visual features could be inherited, or transferred to another object, and how the shine-through illusion occurs. The neural network has two layers (below). Both layers receive visual inputs (blue arrows). Neurons submit their activity to other target neurons through links within and between the layers (red and green arrows). Links originating in Layer A inhibit the activity of target neurons, whereas links originating in Layer B activate target neurons. As in a real brain, the relative strength of a link varies with the distance between neurons.

A computer simulation (right) shows how the activity of the second neuron layer changes over time. When a grating of five parallel double bars appears after a vernier of two slightly staggered bars, neural activity starts developing at the edges of the grating (dark bars in top image). Meanwhile, neural activity in the middle is suppressed by the blocking links. The observer cannot perceive the vernier, because the activity in the lower layer is too short-lived. In the case of a broader, 25-bar grating, which has edges farther away from its center, the activity of the vernier-representing neurons is blocked only weakly and the neurons stay active for a longer time (dashed red oval in middle image). The visual system thus segments the vernier as an independent object from the grating, and so the observer consciously perceives it. When the test subject sees a grating with two gaps (bottom image), neural activity starts building not just at the outer edges but also at the gaps—again, near the vernier. In this instance, the vernier neurons are blocked, and the middle section of the grating inherits the attribute of being aslant.

An Explanatory Model

Feature inheritance and shine-through might be considered as two states of feature binding. In feature inheritance, observers see only one object—the grating—and characteristics that briefly come into view bind to it. In shine-through, study participants perceive two separate entities, but the shine-through element binds the offset feature. (The grating does not.) Any theory about the mechanisms behind this illusion has to explain why the information about the vernier offset is present during both the feature inheritance and shine-through.

Our group has proposed a model of neurological activity that can illustrate our experimental observations and can also foresee under which conditions people will segment visual inputs into objects, bind them to features and perceive them consciously [see box above]. Our work is thus a first step on the long road to understanding how the brain accomplishes the task of differentiating a camel from a palm tree.

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(Further Reading)

- To test your visual perception, go to http://neuro.physik.uni-bremen.de/~vernier/vernier_english/viewseye.html