How our brain constructs what we see

Perception is not simply what our eyes see. Murray & Herrmann (2013) describe the brain mechanisms by which seeing becomes perceiving; a topic with foundations in everyday experiences, philosophy and art, which has been a central theme of neuroscientific research. That perception consists of far more than what is physically present is evident in images like those in the left-most panel of Figure 1. Here, contours are seen in the absence of luminance changes.

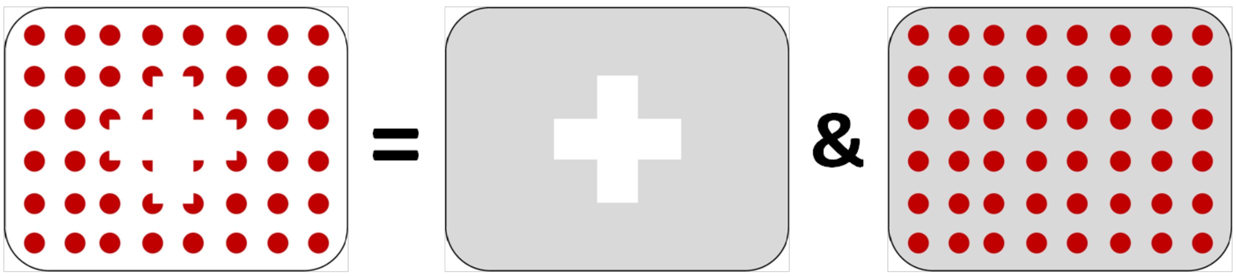

Figure 1. Illusory cross (left of equal sign) and how it is perceived by our visual system (right of equal sign). If you were to describe what you see in the left part of Figure 1, you would most probably say that you see a white cross on top of an array of red disks; almost like a Swiss flag. However, strictly speaking, the cross is formed by segments of circles (pac-men).

Murray & Herrmann (2013) reviewed how the brain binds information together to form stable perceptual representations of objects. They show how vision and perception more generally should not be thought of like a webcam that just takes pictures of the world. This is not a fault in how our brains work, but rather is exemplary of how the brain constructs perception and takes advantage of its massive inter-connectedness in ways that are highly similar to social networks and railway systems. The construction of perception is not only based on the information the eyes capture, but also on information stored in the brain and "guesses" based on this stored information. In the real world, the visual system must handle situations of occlusion or noise. It is likewise often the case in natural vision that we see objects in the background (e.g. the lady in the yellow dress) that are partially occluded by other objects in the foreground (e.g. the man in the yellow sweater) (Figure 2). Despite the lack of visible object borders and the lack of being able to see complete objects, our visual systems are able to segregate the scene into its constituent objects and to group together elements belonging to the same object. Sorting out which parts belong to the same object(s) is a challenging task for the human brain.

Figure 2. Examples of how the visual system is able to sort out which portions of a scene belong to one vs. another object despite equal luminance/color.

Swiss researchers have been at the forefront of this line of investigation, originating in the seminal neurophysiological studies of Rüdiger von der Heydt and Esther Peterhans during the late 1980s in Zurich as well as later in the neuropsychological studies of Patrik Vuilleumier and Theodor Landis during the late 1990s in Geneva. Since Murray's arrival in Switzerland in 2002, he and his colleagues have continued by performing a series of neurophysiological and neuroimaging studies in healthy humans as well as in patients with schizophrenia; the latter of which have prompted hypotheses regarding low-level sensory impairments as a core deficit in neuropsychiatric patients. The work presented in Murray and Herrmann (2013) reconciles competing models of how illusory contours are perceived, with a direct impact on fields including neuroscience, psychology, and computer vision. The construction of visual perception by the human brain takes advantage of at least three features that all work together in concert.

First, there are the anatomical connections – i.e. the wiring. These connections not only describe the way information comes into the brain from the eyes, but also how information circulates around in the brain between "lower" and "higher" visual areas (Figure 3). These connections can be divided into those that go from the outside world into the brain in a manner much like a conveyor belt, which are known as feed-forward pathways because information goes from one station and is fed along to the next station (black arrows in Figure 3), and those that can go from one point inside the brain to another point inside the brain, which are known as feedback or lateral pathways (red arrows in Figure 3).

Second, there are so-called "receptive fields" of neurons, which can be more readily understood as akin to the size of pixels in a digital camera (circles in Figure 3). Some structures like the retina and primary visual cortex have very small receptive fields; their pixels are small and any individual neuron only "sees" a very tiny portion of a scene. As one progresses along the feed-forward anatomical chain, these receptive fields likewise get bigger (schematized by the circle size in Figure 3). The bigger the neuron's receptive field the blurrier is its "view" of the world. Because different neurons share information and "talk" to each other so that the image they collectively "see" can get sharper.

Third is the timing of how information is communicated. On the one hand, information is processed in a serial and feed-forward fashion much like a conveyor belt where a car is assembled piece-by-piece at each station one after the other. On the other hand, information is also processed in a parallel and feedback fashion much like a social network or the Swiss railway system. The lines of a railway network can be understood as similar to connections between different parts of the brain; there is a complex mixture of direct and indirect routes between any two locations both in a railway network and also in the brain. Intersections can be understood as hubs where information can be combined and integrated. Importantly and much like a railway system, information can go in the forwards and backwards directions, and different "lines" can run at different speeds all at the same time, resulting in combinations of express and local information routes. In this way, information can quickly "spread" to different locations of a network.

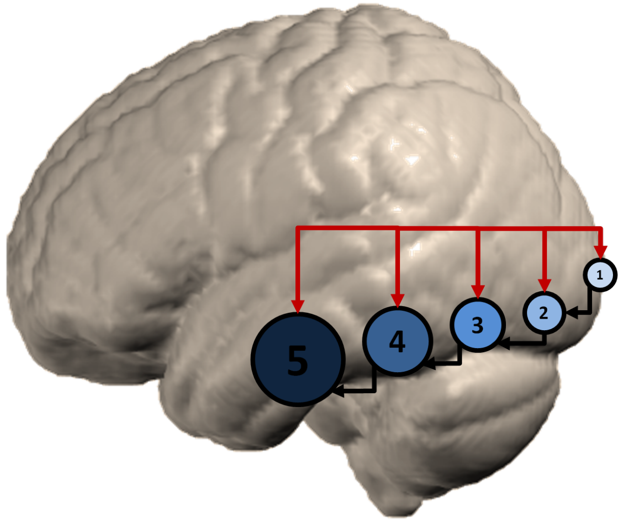

Figure 3. Schematic organization of the visual system showing the left hemisphere of a human brain. The front of the brain is displayed on the left, the back on the right. Lower visual areas receive visual information first and are located in the back of the brain (#1). Higher visual areas get information later and can be found further towards the front of the brain (larger circles/numbers)**. F**eed-forward connections are illustrated by black arrows and feed-back connections by red arrows.

The processing of illusory contours described by Murray and Herrmann (2013) demonstrates nicely how our visual system constructs what we see. Lower stages of processing become active first in detecting simple features of an image. But, these neurons don't 'know' to which objects the detected edges, such as the mouths of the pac-men in Figure 1, belong. Only higher stages of the visual system are able to achieve this task and are first in detecting complex objects. In this regard, these higher stages act as the foremen directing the construction of perception and using feed-back to lower stages to perhaps refine the perceptions we ultimately experience. The magic of illusions is not so much in *what* we perceive, but rather in *how* they show off the capacity of our brains to shape perceptions.