2 fMRI Brain Visuals as Fields for Interaction

fMRI brain visuals are signs in a very straightforward sense: Cognitive neuroscientists observe the human brain and its processes by consulting its fMRI renderings. Alan Gross (2008: 281) has suggested that the character of fMRI brain visuals should be understood in terms of indexical signs. In his proposal, Gross refers to Peirce's[1] famous distinction between *icon*, *index*, and *symbol*,[2] articulated with respect to the relationship between the sign and its object (Peirce, C.P.: 4.531). For Peirce, whereas symbol, most closely related to the Saussurian language-like sign, is a conventional sign denoting its object with respect to a rule, iconic and indexical signs are characterized by their materiality and embodiment. Index is the sign that is physically or causally connected to its referent and thus always bound to specific circumstances of its instantiation. Examples are a pointing finger and footprints in the sand. Icon, on the other hand, is a sign that shares characteristics with the object, perceived as having some similarity with it. Usual examples of icons are a realistic painting and a wax statue.

The indexical character of fMRI visuals is evident in how they are generated. Just as a photograph has a causal relationship with its subject,[3] there is a causal relationship between the brain and its fMRI rendering. However, fMRI visuals are also iconic. The claim for the iconic character of brain visuals, though, should not be equated with a naïve idea of similarity: fMRI visuals are not iconic signs because they look like the brain and its processes. Rather, fMRI visuals are iconic as they are understood through an active visual inspection and embodied engagement. In other words, the iconicity of fMRI visuals comes to the fore when they are considered from the perspective of real-time, practical engagement.

This chapter looks at a published fMRI figure to show that fMRI visuals are not iconic signs in terms of the naïve idea of similarity, but that they generate meaning by relying on a variety of semiotic structures that function as their "infrastructure for seeing." The published fMRI figure does not directly "reveal" to a *passive* eye the brain and its processes; instead, it relies on a variety of signs that indicate what the figure shows as they call upon the viewers' cultural knowledge and experiential engagement. One should, however, ask what functions as the infrastructure for seeing when scientists engage fMRI visuals during their everyday laboratory work.

The question of iconicity and semiotic infrastructure is important for at least two reasons. First, it problematizes the productivity of the dichotomy between the visual and the digital. Second, it calls for a reconceptualization of scientific visuals and their boundaries. fMRI scans, when considered from the perspective of their everyday, real-time engagement, are neither only visual nor only digital; they are at the same time visual and digital. This engagement with brain visuals can be tackled in terms of written as well as gesturally enacted signs. Because they do not generate meaning in the absence of their infrastructure for seeing, such infrastructure is their constitutive element. Digital scientific visuals are, thus, *fields for interaction* as they have to be understood with respect to how they are worked with and experienced. In other words, their character is not necessarily representational, but it concerns the participation of their readers/writers.

In making this argument, the chapter relies on the interpretative semiotics of Peirce and his follower—Umberto Eco. Whereas Peirce speaks to social studies of science and technology through his own writing in the philosophy of science (e.g., Rescher, 1978), I want to highlight some of the features of Peirce's *semeiotic* and *pragmati(ci)sm* not originally aimed at studies of science and less commonly referred to in STS. This overview, however, is not intended as an exposition of the theory that underpins the practice (expounded in the chapters that follow). Rather, it is to clarify some of the concerns that sustain the practice-oriented analysis that constitutes the core of this book. At the same time, in providing empirical examples and analyzing videotaped material of laboratory work and interaction, the goal is to generate a sense of how the next step in engaging Peirce's semiotics in STS can be taken.

Iconicity and fMRI Brain Visuals

In the 1960s and 1970s, semioticians aimed to dismantle iconicity in terms of the naïve idea of similarity, characteristic of our intuitive understanding of visual images (Barthes, 1964; Eco, 1976; Volli, 1972). In accordance with the structuralist tradition, the problem of similarity has been treated in relationship to cultural conventions and codes. Semioticians, when analyzing cultural codes of realistic drawings, cinematic images, and magazine advertisements, wanted, if only partially, to subsume such signs under the umbrella of arbitrariness. This radical position of the early years has been revisited on several occasions. In his most recent book on semiotics, *Kant and Platypus*, Umberto Eco (1999) sets out to somewhat reconsider his original, and what he calls "iconoclast," position. Eco laments that since the peak of the debate, many have been influenced by Peircian semiotics, yet this influence primarily concerned the notion of unlimited semiosis, leaving the theorizing of iconism largely unexplored (Eco, 1999: 342). To deal with this neglect, Eco directs attention toward Peirce's suggestion that iconic signs generate "effects of similarity." For example, even though fMRI brain visuals should not be equated with what they stand for—the brain and its processes—they generate a sense of resemblance with their referents. How should this idea of resemblance be understood?

Although Eco, with Peirce, maintains that the interpretation of the iconic sign contains a perceptual basis,[4] the anchoring of the sign in the material world, however, does not mean that an iconic sign should be equated with the iconic nature of perception. Perceiving a brain and seeing its fMRI rendering, for example, are two different phenomena. To deal with the immediate impression of likeness that iconic signs generate, Eco talks about "surrogates for perceptual stimuli." The idea is that even if under certain conditions a sign generates effects of similarity, we have to acknowledge that these impressions are relative to the surrogates manufactured to generate the effects. To provide an example, Eco talks about a visit to a perfume factory. Experiencing the manufacturing of a perfume highlights the difference between a perceptual iconism and an impression achieved by the way of surrogate stimuli:

> Anyone who has ever visited a perfume factory will have come up against a curious olfactory experience. We can easily recognize (on the level of perceptual experience) the difference between the scent of violets and that of lavender. But when we want

> to produce industrial quantities of essences of violets or lavender (which must produce the same sensation, albeit a little enhanced, stimulated by these plants), the visitor to the factory is assailed by intolerable stenches and foul odors. This means that in order to produce the impression of the scent of violets or lavender, one must mix chemical substances that are most disagreeable to the olfactory sense (even though the result is pleasant). I am not sure nature works like this, but what seems evident is that it is one thing to receive the sensation (fundamental iconism) of the scent of violets and another thing to produce the same impression. This second operation requires the application of various techniques with a view to producing surrogate stimuli. (Eco, 1999: 352)

To figure out the methods that generate the impressions of similarity, Eco talks about the observer whose positioning makes the constructed character of the iconic sign obvious. A visitor to the perfume factory has a different olfactory experience than that of a customer buying a perfume in a department store. Similarly, we can experience a painting as veridical only if we stand at a certain distance from it; if we move too close, the illusion of reality disappears. This means that the surrogate stimuli partly depend on the way in which we engage with them: in the perfume factory versus in the department store, too close to the painting versus at a certain distance from it (Eco, 1999: 353). Thus, instead of discussing the problem of iconicity only in terms of the relationship between the sign and its referent, Eco's comment indicates that we should consider the *acts* of perception as essential elements in the functioning of the sign.

To discuss the apparent tension between the digital and visual character of fMRI brain scans, I want to explore this direction in understanding the iconic sign. However, instead of using the positioning of the viewer to prove that the iconicity is achieved through construction (as is the case in Eco's example), I consider the iconicity in terms of the user/designer's interaction with the visuals.

Scientists use fMRI as a way of identifying specific regions on the human cortex that process types of information. Yet, when they indicate the specialized areas with colorful patches on the cortical surface (see, e.g., figure 2.1 [plate 1] as well as figure 7.1 [plate 2]), they do not intend to show how physical brains appear to sight, but how the brain areas and the information they process are related to or distinctive from each other. To understand and work with such renderings, though, fMRI practitioners actively exploit their visual character. Generated through a series of measurements, fMRI scans depict the otherwise invisible cognitive processes in terms of visuospatial features that, combined with the digital character of brain scans, are engaged in ways that parallel how we treat objects and processes in our everyday world.[5] This mode of engagement with visuospatial signs is exactly where their iconic character comes into play.

The Case of the Published fMRI Figure

Let's start the discussion of iconicity by analyzing the published fMRI brain visual reproduced in figure 2.1 (plate 1). The figure comes from an

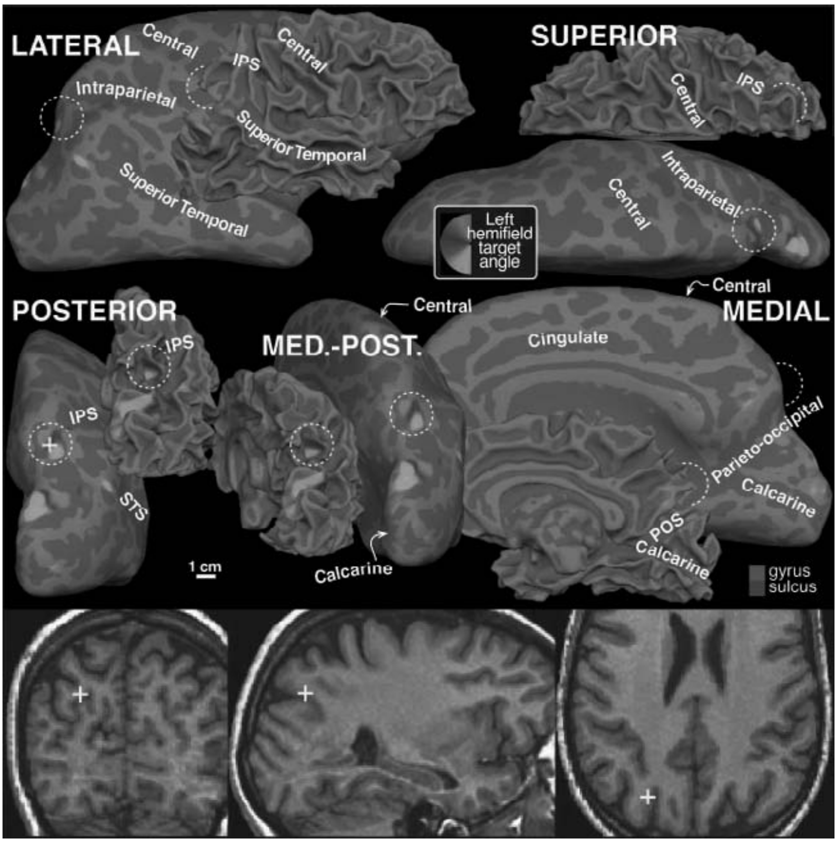


Figure 2.1 (plate 1)
Published fMRI figure from the article by Martin Sereno, Sabrina Pitzalis, and Antigona Martinez entitled "Mapping of Contralateral Space in Retinotopic Coordinates by a Parietal Cortical Area in Humans" (*Science* 2001;294:1350–1354).

article by Martin Sereno, Sabrina Pitzalis, and Antigona Martinez entitled "Mapping of Contralateral Space in Retinotopic Coordinates by a Parietal Cortical Area in Humans," which appeared in *Science* in 2001 (Sereno et al., 2001; fig. 2).[6] The analysis of the figure serves in dissipating the claim that fMRI scans refer to their objects by natural and immediate likeness. In other words, to claim that fMRI brain scans are iconic signs does not have to imply that such renderings need to be understood in terms of naïve iconicity, as their effects of similarity are not necessarily based in a relationship of simple resemblance (or isomorphism) with what they stand for.

First, the figure implies the choices that have been made: it excludes some material while representing other. In this sense, the analysis of the figure highlights elements of the discursive universe that characterizes the field of cognitive neuroscience. The way in which the figure articulates what needs to be seen implies expectations in the field of cognitive neuroscience, while at the same time it reveals innovation and the authors' resistance to dominant forms of representation. Second, the figure is a *supervisual*: it appeals to our senses and embeddedness in the world, showing what our "naked" eyes cannot see. Scientists, by coordinating their seeing with technology, observe the "wrinkled" cortex as a "flat" and "cut" sheet on which temporal processes are depicted as spatial phenomena (as explained by Paul in his interaction with Jane, reported in the previous chapter). This seeing of what cannot be seen relies on the human aptitude to think by exploiting our visual capacity and our skill of handling objects in the world.

The Cerebral Cortex as a Map

The article by Sereno and colleagues (from which figure 2.1 was taken) is an example of the *brain mapping* technique used by scientists to project the results of measured brain activation onto the spatial renderings of the brain. A brief look at the graphical and textual components of figure 2.1 highlights the historically marked, sociocultural elements at play. The figure implicitly refers to arguments around the issues of *localization of function*, *retinotopic mapping* of the visual cortex, and the theoretical differences between claims to the existence of *cortical maps* versus *neuronal modules*.

The concept of human brain mapping and the idea of localization of function primarily refer to the cerebral cortex, the outer structure of the brain (leaving the rest of the brain in the background). The functional role of the cortex was given early attention by the 18th-century mystic Emanuel Swedenborg (1688–1772), who attributed to it sensory, motor, and cognitive functions. In his search for the biological site of the soul, Swedenborg put forward the idea of a somatotopic organization of the motor cortex, where the motor cortex is structured in a map-like fashion containing an array of areas specialized in controlling the movement of different parts of the body (he localized control of the foot in the dorsal cortex, the trunk in an intermediate site, and the face and head in the ventral cortex) (Gross, 1998: 127). Even though Swedenborg's proposal may not have had any effect on the development of neuroscience (Gross, 1997), the idea of localizing specific brain function in the cerebral cortex persisted.

This privileging of the brain cortex, whose understanding involved making a map and localizing its functions, was further developed by phrenologists Josef Gall (1758–1828) and Johann Spurzheim (1776–1832). Despite the fact that the phrenological enterprise, whose goal was to identify an individual's mental faculties through the measures of her or his skull, is not considered scientifically valid, Gall and Spurzheim's proposal of a correlation of function with cortical locations is still respected. For example, John Allman (a contemporary neuroscientist well known for his studies of primate cognition) notes that: "The phrenological maps are pure fantasy without any basis in experimental or clinical observations. However, the phrenologists can be credited with the general idea that functions are localized in particular places in the brain" (Allman, 1999: 31). Research on function localization continued its development in the work of some of the early modern experimental neurobiologists, such as Pierre Flourens (1794–1867), Paul Broca (1824–1880), and John Hughlings Jackson (1835–1911) (see, e.g., Star, 1989), reaching new heights in contemporary fMRI research.

This preoccupation with the brain cortex and the interest in localization of brain function is clearly exemplified by figure 2.1. The figure is a result of a computational transformation, which fMRI practitioners call *surface reconstruction*, where the data represented by a series of "raw" anatomic scans are merged into one single visual. Through the process of making the cortex visible, however, the rest of the brain is selected out so that the cortical renderings can be employed as a substrate on which functional data (standing for brain processes) are projected. These depictions of the brain function concern the topographic predictions, or so-called retinotopic maps, used to describe the organization of the visual cortex.[7]

The proposal of topographic organization of the visual cortex has a noteworthy history. While its origins can be traced back to the work of the Arab visual scientist ibn al-Haytham (965–1039) (Gross, 1998: 76), the first to experimentally reveal this organization were "lesions studies," or studies of damage to delimited areas of the brain. The lesions studies in animals, as well as naturally occurring lesions in humans, were used to show that the visual field, and hence the retina, is represented within the cortex in a very orderly fashion, where adjacent locations in the visual field are represented in adjacent locations in the cortex. Particularly well known are studies of soldiers who suffered head injuries in the Russo-Japanese War (the work of Japanese ophthalmologist Tatsuji Inouye) and in World War I (the research of British neurologist Sir Gordon Holmes) (Kauffmann Jokl & Hiyama, 2007). Today, the enterprise of mapping the visual cortex with fMRI is regarded as one of the most promising research areas in the field of cognitive neuroscience.

According to the present-day knowledge in neuroscience, the human visual cortex, located in the posterior part of each hemisphere, consists of multiple areas. Once the information arrives from the eyes, via visual pathways, to visual centers of the brain, it is passed from multiple areas located in the early visual cortex to the areas of the higher-order visual cortex. The early visual areas tend to encode more elementary features, such as lines, whereas higher-order visual areas contain neuronal groups that encode more complex features, such as edges, curves, and composition of features. Scientists know that the early visual areas preserve the topography of the visual field, but, as Sereno and colleagues' article indicates, they are interested in finding out if the higher-order visual areas are retinotopically organized as well.

As reported in the article, the process of identifying retinotopic maps on the cortical surface involves the presentation of a patterned stimuli moving through the field of view of a subject being scanned. Due to the temporal match between the stimulus and the neuronal response, the scientists identify which parts of the visual cortex process stimuli in specific points of the visual scene. Scientists use such reproductions of spatial (not pictorial) relations in the brain cortex to assess the location and borders of a specific brain area.[8] These kinds of areas are represented in plate 1 as multicolored patches on the gray surface of the cortical anatomy.

When describing the functional organization of a specific region of the human cortex, fMRI practitioners refer to each of the brain activations or their clustering in terms of *maps* and *modules* (Op de Beeck, Haushofer, & Kanwisher, 2008). Thus, in addition to seeing the entire cortex of the human brain as a map,[9] scientists also use the term *map* to denote the organization of specific functional areas. For example, scientists who study the retinotopic organization of the visual cortex talk about map-like organizations on the visual cortex.

The two labels—maps and modules—evoke an important debate in the contemporary study of the human mind. The proponents of modules argue for the existence of areas that selectively respond to the specific stimuli, where such regions are discontinuous, showing a clear difference in the neuronal response across their boundaries. On the other hand, the map-like organization, like the one depicted in figure 2.1, indicates a gradual shift in the peak of neuronal activation, considered to be a part of a larger-scale cortical map. The idea of the neuronal module in neuroscience is often associated with what may be defined as a more complex and theoretically committed concept of *module* in cognitive science as used by the proponents of the argument for *modularity of mind*. Philosopher Jerry Fodor (1983), drawing on the linguistic theory of Noam Chomsky, argued that the mind is composed of domain-specific and genetically specified functional units. The idea, resembling some aspects of phrenology (Uttal, 2001), was criticized by the proponents of *connectionism* (e.g., Elman et al., 1996) and other more recent cognitive science trends that argue for the concept of *network* in understanding of the brain functioning. These trends propose that mental phenomena should be seen as emergent effects of larger networks (associated with multiple brain locations).

By pointing out the existence of a map-like organization, rather than a module, figure 2.1 indicates the positioning of its authors in the debate: They mark themselves as interested in connections between localized areas and thus farther removed from the claims for the modularity of mind. In this sense, the fMRI visual (as a depiction of cerebral cortex that indicates the geographic organization of brain processes) not only shows its sociocultural articulation but also connotes alignments and takes positions.

How the fMRI Figure Indicates Brain Activations

Compared with other neuroimaging techniques such as *electroencephalography* (EEG) and *magnetoencephalography* (MEG), which generate more precise information about the temporal dynamics of electrophysiologic processes occurring in the millisecond range, the metabolic imaging techniques such as fMRI[10] provide a rougher picture of the temporal dynamics but are extremely powerful in localizing brain structures that are active during a cognitive task (Pulvermüller, 1999). Cognitive neuroscientists see the promise of fMRI technique in its capacity to noninvasively generate high-resolution brain visuals used to identify where in the human brain specific cognitive processes take place. In this sense, the scans are conceived as maps, intended to point out location and relationship among brain activations. Though the idea of visual cortex as a map already has a long and intricate history (as pointed out in the previous section), the way in which fMRI figures indicate the existence and location of cognitive processes reveals their complex sociocultural character. With its colors, legends, textual and graphical labels, all enrolled to indicate where a brain activation is located, an fMRI brain visual does not simply resemble the brain that was scanned.

One of the immediately noticeable elements of figure 2.1 is the labels located across the brain scans. To indicate general patterns in the locations of brain activations and relationships among them, fMRI researchers have to deal with the individuality of every human brain (just like with our faces, there is a significant variation in the anatomy of our brains). To confront the individuality, as they point out the generality of the research findings, fMRI figures are labeled. These labels, used not only by the "untrained eye," but also by the "expert reader," indicate where on the human cortex the relevant activations are located.

There are multiple labeling systems adopted by the fMRI community (Brett, Johnsrude, & Owen, 2002), none of which is *theory free*. Each of the labeling systems, while enjoying different levels of popularity, implies the positioning of its users in the field of cognitive neuroscience. By choosing one labeling system over another, fMRI practitioners, for example, indicate their position in the maps versus modules debate.

Those scientists who, like Sereno and his colleagues, talk about brain activations in terms of maps tend to be interested in lower-level cognition (such as visual and auditory processing, instead of linguistic and conceptual issues) and cross-species comparison. As exemplified by figure 2.1, to convey the shape and the exact extent of the activation area, they often represent data sets collected from single persons (avoiding averaging across multiple sets) with a goal of preserving the fine-grained elements of individual data. Typically, these scientists use as their main labeling technique a type of system based on the anatomy of the human brain.

The Sereno et al. article suggests that in addition to the well-known retinotopic areas in the early human visual cortex, there are also retinotopic maps in the higher-order visual areas. The article reports the finding of a map, whose function is to represent the angle of a remembered target, located at the border between the visual and somatosensory cortices. To function as evidence for such a claim,[11] figure 2.1 marks the location of brain activations with respect to the well-known anatomic formations such as the sulci, or grooves, on the brain cortex. This labeling system is visible in the several layers of graphical signs inscribed over the brain visuals.

The figure uses text labels, dotted circles, and legends for colors and scale to situate the brain activations with respect to the positions of the important brain sulci.[12] The anatomic structures are not marked to teach the viewer about their location, but to position the activation sites. In accordance with the enterprise of function localization, the gaze needs to be directed toward the activations on the cortical sheet, which are circled by the white dots and situated in relationship to the sulci indexed by the text labels.

To distinguish and locate the brain activation on the cortical map, the labels and other graphical signs are, furthermore, coordinated with colors that can be sorted into three distinct groups: the colors associated with the background, the structural representations of the cortex, and the maps of remembered targets (see plate 1). The background, whose role is only to contrast what is of interest and has no intrinsic importance on its own, is black. This black "background" erases the cortical representation of the left hemisphere and the rest of the body of the person being imaged.[13] In contrast, the structural scans that represent what is static are in tones of gray. These gray renderings make visible the anatomy (or structure) of the brain on which the maps of the brain processes (its function) are overlaid. The figure also provides a legend to indicate what the gray tones stand for: the lighter gray signifies the existence of a gyrus (or a convolution of the brain), and the darker gray indicates the presence of a sulcus, signifying the three-dimensionality of the space represented as two-dimensional.[14]

In contrast, the portions of the cortex that are considered to be of primary interest are indicated with brightly colored patches of red, blue, and green. The bright colors show what part of the human brain is active when "processing contralateral remembered targets." In other words, the difference in colors, derived through the calculation of the temporal match between the stimuli and the neuronal response, codes the phases of visual processing understood as a response to changes in the visual scene. As the choice of color is not standardized, the caption and legends provide an explanation of what different colors stand for.[15] Similar to the use of "false colors" in Earth-satellite photography and astronomy (Ihde, 1998: 92; Lynch, 1991), fMRI visuals that indicate brain activations with bright colors are marked to guide the gaze and indicate, rather than represent, the world in a truthful manner.

In sum, the way in which fMRI figures designate brain activations and their location entails a series of choices. Figure 2.1 shows cortical maps by situating their renderings with respect to the anatomic landmarks. This operation is generated by using an array of semiotic structures—textual and graphical signs—which mark what is relevant and how it should be read. The way the figure guides the viewer's gaze over its territory is another element that complicates the relationship between the fMRI scan and the brain functions.

The fMRI Figure as a Supervisual

The idea of naïve iconicity is further negated by the "super" character of fMRI brain visuals. Figure 2.1 is a supervisual in at least two senses: it represents temporal changes (function) in terms of spatial phenomena (indicated in different colors, as explained above), and it displays the anatomy of the brain in ways that exceed what an unaided human eye can see.

By representing the activations as patches on the cortical surface, figure 2.1 shows as visible and spatial phenomena the invisible and temporal events. These visuospatial signs, inscribed on the renderings of the brain function as translations of temporal events, are another reminder that fMRI visuals cannot be simply judged in terms of resemblance with their referents.

Figure 2.1 is also a superimage because of the way it shows its material structure (not only its brain processes). Even though in the case of brain anatomy fMRI visuals depict what is spatial and potentially visible (beneath the skin and skull), in many ways they show what is *not* accessible to the human eye outside the digital realm. The frequently used digital transformation that generates so-called flattened maps (as discussed in chapter 1) illustrates this point. The technique produces the renderings of the brain cortex where the characteristic brain fissures (or sulci) and convolutions (or gyri) are all depicted as positioned on the same plane so that two-dimensional (2D) representations allow for an improved visual inspection of experimental data.

By generating visuals that resemble less and less what they stand for, scientists are able to enhance the production of knowledge through sight. As the labels written in capital letters indicate, figure 2.1 displays the cortical sheet as if it were cut into pieces. The figure shows the right hemisphere superior parietal cortex from five different views: *lateral*, *superior*, *posterior*, *medial-posterior*, and *medial*. This cancellation of just one physically situated point of view is another way to provide the viewer with an enhanced gaze that sees the three-dimensional (3D) structure in an omniscient manner.

When Sereno and colleagues talk about "inflating," "cutting," "spreading out," and "flattening" the cortical surface, they refer to the fMRI computer program designed by the first author of the article. The computer program performs digital transformations of experimental data understood in terms of physical actions. According to the authors, although the representation of a 3D folded cortex preserves a more "natural" appearance, this type of visual rendering does not show what is buried in the fissures on the surface of the brain. Because of the high percentage of concealed cortical structures, "distance measured in 3D space between two points on the cortical surface will substantially underestimate the true distance along the cortical sheet, particularly in cases where the points lie on different banks of a sulcus" (Fischl, Sereno, Tootell, & Dale, 1999: 273). Hence, the technologically enhanced "unfolded" visual, even though further removed from the actual appearance of the biological brain, allows a more precise understanding of the cortex, as this "cyborg view" (the coordination of digital technology with the human eye) enables the viewer to acquire knowledge through a “superseeing.” By looking at figure 2.1, the viewer learns about human cognition as she sees the invisible brain processes displayed over the cortical map whose renderings are cut and flattened by means of a digital manipulation of fMRI data. While showing this “invisible reality,” the figure evokes the digital processes, given as concrete actions, that have been accomplished to enable its showing.

Multivoicedness of the fMRI Figure

A strong social shaping of fMRI visuals is exemplified by the multiplicity of human voices (Bakhtin, 1981) that figure 2.1 inscribes. The labels, numbers, and legends in figure 2.1 indicate the voices of a larger scientific community (or, even broader societal forces) as well as the voices of the figure’s authors. The way these voices intertwine is complex. When inscribed over fMRI visuals, the semiotic structures reveal a propensity toward standardization—characteristic of the field of cognitive neuroscience—while implying local resistances and negotiations introduced in the figure by its authors. In other words, the visual organization of the figure not only indicates an array of players involved in its fashioning but also shows their antithetical positions and their, often just momentary, reconciliations.

As pointed out in the previous section, the flattened renderings displayed in figure 2.1 are generated to enhance visibility. Somewhat ironically, to be readable by a wider audience interested in the localization of function but tormented by the individual variations, these supervisuals have to refer to other types of representations. Figure 2.1 provides two kinds of brain visuals: In addition to the renderings produced with the program for data analysis designed in Sereno’s laboratory (the supervisuals), the bottom row of the figure displays the more commonly seen renderings of the brain structure. These structural representations of the brain slices—coronal, sagittal, and axial—refer the supervisuals to the standard as they, by way of the yellow cross, indicate the center of the parietal maps on the supervisuals. The linking of the two types of visuals not only explains the meaning of one set with respect to the other set but also indicates a tie between the widely accepted and the local.

As the caption of figure 2.1 explains, the supervisuals are obtained from data collected from a single experimental subject. The authors' aim is to describe a specific map on the human cortex that, they believe, can be most precisely viewed when the cortex of one person is shown. By explicitly pointing out that the figure represents the cortex of a single brain, the caption acknowledges its somewhat exceptional status. The more common procedure, shaped by the overreaching goal to find out how the human brain *in general* (rather than an individual brain) processes information, is to statistically analyze the data of multiple individuals and then overlay them on the renderings of brain anatomies merged into one single structure.

When working with experimental data collected by scanning multiple individuals, fMRI researchers commonly use the well-known *spatial normalization* procedure specified in Talairach and Tournoux's stereotaxic atlas (Talairach et al., 1967; Talairach & Tournoux, 1988). The procedure consists of a scaling method according to which each brain representation can be proportionally transformed to match roughly another brain representation in overall size and shape. Once the data have been scaled, researchers compare them with the "standard brain" or "Talairach brain" in the atlas. The Talairach brain is composed of photographed and labeled brain sections—axial, sagittal, and coronal brain slices—from one hemisphere of a 60-year-old French woman, indicating how the drive to achieve generality often erases particularity.

The brain activations in "normalized" data are often reported in terms of stereotaxic coordinates where every point in the brain is labeled with respect to the same, well-known geography.[16] Figure 2.1, however, does not obediently follow this procedure. As already mentioned, to localize brain activation the figure uses an alternative labeling system based on the anatomy of the human brain: The map of remembered angle is identified by specifying the position of the brain sulci and relating the activation to them. This type of labeling exhibits resistance to the widely used standardization system as it reflects the interest, training, and positioning of the authors in the field of cognitive neuroscience. From the choice of the labeling system, the viewer can read that the authors aim to show the geography of the human cortex with more accuracy, especially with regard to the visual cortex, where the position and shape of sulci are less variable across individuals. The labeling further indicates that the authors are interested in a comparison between the results obtained from the human brain and the brains of other species, as their labeling system is known to be advantageous in cross-species research. In contrast, the authors find the Talairach approach (based on 3D stereotaxic coordinates, rather than on position relative to the 2D cortical sheet) to be deficient. This is particularly the case when the location of interest is sited near a deep fissure on the cortex, as a small change in coordinate could generate a significant error, corresponding with a large change in distance across the cortical surface.[17]

Nevertheless, figure 2.1 translates the results of the study into the Talairach coordinate system, consenting to the more general and expected procedures. In addition to relating the found activations to sulci on the cortex, the authors specify the location of the activations in the Talairach coordinate system—the format accepted and used by the cognitive neuroscience community at large. In fact, the caption of the figure indicates how to locate the activation maps on the supervisuals through Talairach coordinates, specifying that the center of the map corresponds with three coordinates: $x = 32$, $y = -68$, $z = 46$ (referring to left-right, posterior-anterior, and ventral-dorsal dimensions, respectively). In this way, the figure, while implying a tension and possibly an attempt to destabilize current practices, inscribes a dialogue between the group of researchers and the standardization procedures endorsed by the larger scientific community.[18]

The Model Reader and Reading Brain Visuals

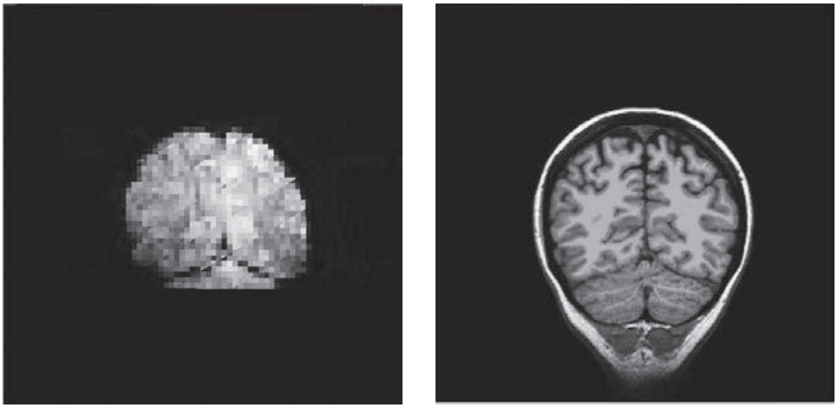
Figure 2.1 connotes a series of decisions about the ways in which brain activations are conceptualized (e.g., maps versus modules) and how different labeling methods (e.g., macroanatomy versus stereotaxic coordinates) are conceived and negotiated. By enlisting colors, legends, and other textual and graphical strategies to indicate what needs to be seen, the appearance of the figure also shows how fMRI data were handled (e.g., flattened, cut, and color enhanced). This articulation of the fMRI figure (1) disapproves the possibility of treating fMRI brain visuals in terms of naïve iconicity and (2) indicates the central role of the reader of such visuals. Though not necessarily implying conventionality (in other words, the figure is not simply Peirce's symbolic sign), the figure needs a knowledgeable eye to be comprehended. In other words, when students of cognitive neuroscience first encounter fMRI data, they have to learn how to "see" what the data represent to align their readings with the *model reader* (Eco, 1979, 1990) of such data.

According to Umberto Eco, every text is incomplete, demanding cooperative acts of interpretation to actualize its meanings. At the same time, the text is not open to just any kind of interpretation but demands specific readings. The text anticipates and directs its interpretations by providing indices that guide the reader's inferences, steering the interpretations toward the preestablished courses of reading. The text aims to organize its readings so that its meaning can be understood in the most suitable way. This textual strategy is the text's model reader.

As our reading of figure 2.1 indicates, the fMRI visual inscribes its model reader as it provides, at the level of expression, indices for its expected reading. To show where in the brain cognitive processes occur, a published fMRI figure comes to its readers as a composite field made up of multiple semiotic layers that point out how the brain scan should be read. Figure 2.1 couples the brain scan with the text of the article, the caption, and the graphical marks laid over the scan to allow its reader to *see* what the scan *shows*. These semiotic elements function as its infrastructure for seeing.

In Eco's proposal of the model reader, the text is considered to be independent from the intentions of its empirical author and the effects that it may have on its empirical readers.[19] The position, reflecting larger trends in textual analysis and semiotics (especially its structuralist tradition), intentionally avoids individual empirical readings to focus on the internal coherence of the text, as the attention is directed toward the ways in which the text itself inscribes its instructions for reading.

The analysis of the discursive strategies present in figure 2.1 implicitly assumed Eco's idea of the model reader as we discussed the cultural knowledge that the fMRI published figure demands. We took for granted an ideal reader who is familiar with the location of the superior temporal sulcus, who knows what Talairach coordinates refer to, and is informed about procedures through which digital brains are handled in the laboratory. This reader, as an abstract strategy of the text, is able to identify the *connotative* (Barthes, 1972) dimensions of meaning that the labels, the color legends, and the multiple graphical styles of the brain visuals imply. She uses an array of semiotic layers to understand the aims, general values, and the debates that characterize the research field in which the published figure



(a) (b)

Figure 2.2
(a) Functional and (b) structural fMRI brain visuals.

participates while perceiving the effects of similarity that it generates. In indicating this competency, my goal was not to force the "optimal" readings on the text. Instead, I wanted to point out that this competency evokes the researchers' work in the laboratory.

Take, for example, figure 2.2. After experimental data have been recorded in scanning facilities, the visuals look like the two corresponding brain scans in figure 2.2. The difference between this figure and figure 2.1 (the presence of colors, graphical and textual signs inscribed over the brain renderings, and their composite character) suggests the laboratory work that has taken place between the moment in which a brain scan has been collected and the moment in which the corresponding scientific results have been published. To produce publishable results, the scanning sessions must be followed by months of tight coordination between digital technology and human labor. That coordination, directed at generating the infrastructure for seeing, inscribes its model reader. Yet again, what functions as the infrastructure for seeing during the everyday work in the laboratory? How is such infrastructure articulated?

To uncover the infrastructure for seeing not only in terms of the signs inscribed on the paper but also as ephemeral semiotic acts performed in the laboratory, we must go beyond the idea of model reader to take into account the interactional and phenomenological aspects of empirical readings. We have to consider how scientists inscribe the model readers in the fMRI visuals that they prepare for publication. These interactions not only show how the semiotic layers that participate in generating the meaning of fMRI visuals are enacted in practice but also illustrate the iconic character of such signs. While the recall of practical dealings in the idea of supervisuals already evokes the iconic quality of fMRI renderings, their iconicity irrupts with all its force once the attention is directed toward the real-time interaction in the laboratory (what *can* be seen and directly experienced).

In making this turn from the textual analysis to the description of multimodal practices, the effects of similarity show themselves in how fMRI visuals partake in the materiality of the embodied practice. Their "likeness" concerns how they afford action in the lived world of their readers/writers.

fMRI Brain Visuals as Diagrams

Peirce has explained that iconic signs, in addition to being images, can also be diagrams and metaphors (e.g., Peirce, C.P.: 2.277). Images are the iconic signs that have the same simple quality as their objects, diagrams are the signs whose parts have analogous relations to those of their objects, and metaphors are the icons that show the representative character of a sign by indicating a parallelism in something else. Thus, a portrait would be an example of the image; a map would be an example of the diagram; and a knife could be treated as a metaphoric sign that stands for a gun because both knives and guns can be used for killing. Since we see fMRI brain renderings as a part of our visualized world, we are prone to slip into understanding them as purely image-like. It is, however, more productive to think about fMRI visuals in terms of diagrams as it takes into account how practitioners deal with them.

Scholars agree that the meaning of the diagram in Peirce's philosophy is much broader than our everyday use of the word diagram (Shin, 2002).[20] A diagram, thus, consists of representational elements and the rules that allow for the manipulation of such elements.[21] According to Peirce, a good diagrammatic system should be "mainly an Icon" so that the parts of the diagram are related to each other in the same way that the represented elements are related to each other (Peirce, C.P.: 4.531). Peirce's aim was to show that diagrammatic signs allow experimentation and generate insight as they can be used to draw new conclusions about the relations existing in the world.

To explain the importance of this account for the case of fMRI visuals, consider a passage from Peirce's 1906 "Prolegomena to an Apology for Pragmatism." The essay opens with the writer's explicit invitation to the reader: "Come on, my Reader, and let us construct a diagram to illustrate the general course of thought; I mean a System of diagrammatization by means of which any course of thought can be represented with exactitude" (Peirce, C.P.: 4.530). This initial claim, stating that the diagram can be used to render the dynamics of the thought, is followed by an adversarial question: "But why do that, when the thought itself is present to us?" The writer explains that this question, inquiring into the function of signs, has been posed to him frequently. Among those who raised the point were "superior intelligences," including "an eminent and glorious General." This general is the writer's interlocutor in the imaginary dialogue that follows:

> Recluse that I am, I was not ready with the counter-question, which should have run, "General, you make use of maps during a campaign, I believe. But why should you do so, when the country they represent is right there?" Thereupon, had he replied that he found details in the maps that were so far from being "right there," that they were within the enemy's lines, I ought to have pressed the question, "Am I right, then, in understanding that, if you were thoroughly and perfectly familiar with the country, as for example, if it lay just about the scenes of your childhood, no map of it would then be of the smallest use to you in laying out your detailed plans?" To that he could only have rejoined, "No, I do not say that, since I might probably desire the maps to stick pins into, so as to mark each anticipated day's change in the situations of the two armies." To that again, my sur-rejoinder should have been, "Well, General, that precisely corresponds to the advantages of a diagram of the course of a discussion. Indeed, just there, where you have so clearly pointed it out, lies the advantage of diagrams in general. Namely, if I may try to state the matter after you, one can make exact experiments upon uniform diagrams; and when one does so, one must keep a bright lookout for unintended and unexpected changes thereby brought about in the relations of different significant parts of the diagram to one another. Such operations upon diagrams, whether external or imaginary, take the place of the experiments upon real things that one performs in chemical and physical research. Chemists have ere now, I need not say, described experimentation as the putting of questions to Nature. Just so, experiments upon diagrams are questions put to the Nature of the relations concerned. (Peirce, C.P.: 4.530)

In Peirce's view, diagrammatic signs show what cannot be observed otherwise while consenting for engagement. This engagement has the potential for generating insights regarding the relationship between the represented elements. In Peirce's story, the general uses the map to stick pins into so that he can observe the deployment of forces in a battle. Because the pins on the map are related to each other in the same way that the activities of the two armies are related to each other, the general can comprehend the relationships of activities that take place over the territory and thus adapt his actions to the anticipated changes. Peirce sees the experimentation on the map as an act analogous to the experimentation in the real world: Like chemists, who in their laboratories learn about the chemical reactions in the real word, the general, by observing the map and sticking pins into it, learns about the relationship between the activities of the real-world armies.

fMRI visuals, as maps of the human cortex, are designed to depict relations among the processes that take place on the brain cortex. The diagrams as iconic signs, in addition to representing, allow for observation of the relationships between represented elements so that such relationships can be experimented with. fMRI researchers learn about the workings of human cognition by observing where on the brain cortex clusters of neurons with a specific function are located and what is their relationship to the brain processes situated in other areas. When engaged in the intricacies of laboratory work, cognitive neuroscientists, like the general who uses the pins on the map to understand the relationships between the two armies, use fMRI visuals to conceptualize the relation between the brain areas and their processes. The engagement with the diagram can be accomplished in the imagination but also, akin to the rearrangement of the pins on the general's map, by direct involvement.

Visual and Digital as Mutually Codependent

The argument for the iconic character of fMRI brain scans has consequences for the understanding of the apparent dichotomy between the numerical and visual character of brain scans. When investigating social aspects of MRI, fMRI, and PET, researchers have been busy discussing this distinction (e.g., Beaulieu, 2002; Dumit, 2004, Joyce, 2005, 2008). Anne Beaulieu (2002), when interviewing neuroscientists, found out that they highlight the potential of brain imaging measurement to render spatial components and anatomic referents while, at the same time, they downplay the visual form this information takes to emphasize the quantitative information it represents. Beaulieu understands this negation of the importance of visual knowledge in brain mapping research as related to the way evidence is evaluated in modern Western science. She argues that because visual evidence has been regarded as appealing first to the senses, as opposed to reason, and hence is seen as lacking a solid relationship to the truth, visual evidence is judged as not having a particularly high position in the hierarchy of types of scientific evidence. The interviewees claim that those most interested in the visual aspects of brain mapping techniques are usually clinicians, not scientists, suggesting a hierarchy in which the visual is associated with the lower echelon of applied research.

Kelly Joyce (2005, 2008), who studied the use of MRI in clinical settings, agrees with the claim of Beaulieu's interviewees. In introducing the history of MRI, Joyce describes how Paul Lauterbur, an American chemist credited as the first person to use MRI to generate visuals of human anatomy, talked about those renderings in terms of maps, rather than images and pictures, defining them as a "mathematical representation of spatial information" (Joyce, 2008: 32). Joyce, in contrast, points out that clinical practitioners prototypically talk about pictures of the human body, as their language reflects the saturation with the visual and visible that characterizes our contemporary life:

> Today, language that highlights the relation of the image to pictures of the anatomical body are often used in clinical practice, while language that calls attention to maps and spatiality is less common. . . . This linguistic difference occurs in part because of the broader recognition of the centrality of images to contemporary life as visualizing technologies such as cameras, computers, video games, and picture-producing cell phones become more common. (Joyce, 2008: 32)

Discussions of the tension between the visual and the numerical, and the decision to talk about "pictures" and "images" when referring to MRI, fMRI, and PET visuals, are important. On the one hand, they document how practitioners rationalize and talk about their work; on the other hand, they highlight the pervasiveness of the current focus on scientific texts, larger communities, and societal phenomena in social studies of science and technology. Yet, once we turn our gaze to the real-time practical work in neuroscience, and we adopt the understanding of brain visuals in terms of iconic signs, this dichotomy disappears. Rather than associating the visual character of fMRI visuals with transparency while also coupling their digitality with mediation, interpretation, and choice, the analysis of laboratory work shows visual and digital as mutually codependent. Because of their diagrammatic character, fMRI brain scans are at the same time visual and digital.

fMRI Brain Visuals as a Field for Interaction

The claim that scientific visuals, such as fMRI brain scans, are diagrams (rather than images) has consequences for the definition of their boundaries. The visibility of diagrammatic signs concerns the eyes as well as the hands. These signs, rather than being well-defined and self-standing representational objects, are fields for interaction—they acquire their meaning through work and interaction in the cognitive neuroscience laboratory.[22]

Because the digital character of the matter shapes laboratory practices, fMRI researchers deal with their experimental data in an engaged manner. First, the researchers work with fMRI visuals by placing their hands on the keyboards to generate observable effects in the displayed data. Also, they often use their hands to coordinate computer screens with maps, charts, atlases, and laboratory instruments. Finally, they gesture to *highlight* the features of the brain map or to *enact* what is still invisible in it. Similar to the general's pins and the acts of placing them on the map, these gestures mark or further perform what needs to be seen on the brain scans. In this regard, the researchers' engagement parallels the variety of semiotic forms involved in making the published brain figures meaningful.

The marks on the paper and the fine orchestrations of semiotic bodies and technologies in the shared environment of practice are and evoke practical actions. The researchers (just like the model readers of their publications) understand fMRI visuals in terms of what was, can, and should be done with them.[23] Practitioners' gestures, their touching, and their modification of scientific visuals (directly enacted or evoked) are the constitutive element of these visuals.

The centrality of an embodied engagement, however, concerns not only the digital but also the visual character of fMRI brain scans. When scientists work with fMRI scans, their seeing is accomplished through a coordination of eyes with the action of the hands, ears, and the workings of an array of fMRI technologies. Consequently, the viewing of fMRI visuals is about an active, distributed involvement where the contribution of each of its constituents is indispensable. In fact, the relationship with the digital screens, which suggests an understanding that in many respects is analogous to the physical engagement, would not be possible (at least not to this extent) if the data the scientists were dealing were not given in the visual format.[24]

This understanding of scientific visuals as fields for interaction is parallel to a variety of projects, ranging from art to architecture, where the authors continue their relationship with the objects of their creation beyond the moment after which, traditionally, those objects would have been considered self-standing. To comprehend the character of digital scientific visuals, social scientists have to proceed in a manner similar to artists who observe their work on a display or architects who stay informed on the specifics of a completed building. One example is the photographic opus of the artist JR (http://www.jr-art.net/). JR exhibits his portraits in public spaces, copying, magnifying, and fixing these portraits with wallpaper paste to the sides of buildings, to then photograph the exhibited portraits as they are lived. In such a way, the artist expands the borders of the work of art to include the interaction with and around it. Thus, those activities, traditionally considered to be located outside the external fringes of the photograph, are now a part of the work of art. Another example of this trend can be seen in the practices of the architects James Timberlake and Steven Kieran. As Timberlake pointed out in an interview with Deven Golden (2008), the two architects, in their effort to lower the energy footprint of their buildings, continue to monitor the performance of their projects even after the building has been completed. Using microprocessors to send relevant data from the building to their office, Timberlake and Kieran remain informed on the energy consumption, sustaining an ongoing rapport with the building and its life. We, like artists and architects who include the practical activities in the objects of their creation, need to take into account how scientists participate in generating the meaning of the visuals through their work, interaction, and the inscription of signs that evoke practical engagement.

Although this shift from a representational object to a process of its enactment entails a turn toward the agent, it does not, however, imply either an argument for the psychological and individualistic analysis of meaning or a return to the Author. Instead, the attention to the details of multimodal interaction between scientists and brain visuals indicates a process of distribution and delegation. In the fMRI laboratory, the work of science is accomplished by bringing together human actors, technology, and the multiplicity of semiotic means. The details of this process bring forth an alternative idea of meaning-making where the individualistic mind is an effect of the ability to engage our experiential bodies in the lived world. What matters then are the efforts in documenting the coordination across multiple embodied and social agents, technology, and multimodal semiotic acts.