The space inside the skull: digital representations, brain mapping and cognitive neuroscience in the decade of the brain

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Citation for published version (APA):

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Chapter 4 Images Are Not the (Only) Truth

This chapter considers a love-hate relationship between scientists and their object: the case of the iconoclastic imager. It considers this paradoxical stance as the result of the formation of an interdisciplinary approach that brings together a number of scientific traditions and their particular standards of what constitutes scientific evidence (its ‘empirics’). By examining the various ways in which images are deployed and rejected, I will trace some of the origins of these conflicting tendencies to the technological, methodological and institutional elements in the work of functional imagers. Beyond ‘making sense’ of this paradox, anthropologically speaking, this chapter will provide insight into the current demarcation of imaging with regards to the medical and scientific communities. Since that demarcation primarily revolves around the use of representations, it will also contribute to the discussion about the growing use of authoritative imaging in technoscientific culture. As any and all images become possible, there remains the need for guidelines for “choosing which permutations are acceptable—regardless of technological feasibility (Stafford, 1996).” It is precisely such a case of complex rule-making that I will examine here.

In order to make this argument I will be considering changing and contrasting definition of what I, as a student of the visual, would call ‘images’ in brain mapping. I will use the term ‘representation’ to describe this changing object which has different meanings in the neuroscientific sphere, in the popular domain and in my own discussion. This term will allow me to discuss the ways in which meanings are contested, negotiated or simply taken for granted. It will allow me to highlight the unacknowledged work performed with representations—the work involved in inscribing them in a pictorial or graphical tradition, of making them pictures or graphs. Finally, this neutral term may also be a useful boundary object with which to enter into a dialogue with the various groups who produce these representations.

Types of representations of scientific knowledge have traditionally been ordered hierarchically in modern Western Science, with images and some forms of visual knowing generally low on the scale (Stafford, 1991, 1996; Cartwright, 1992, 1995). This hierarchy relies on the ordering of ways of knowing the world, which provide better or worse access to truth about the way things are, appealing merely to the senses (perception) or to the mind (reason). This ordering of image/text/number is not absolute, however, and there are other ways of constituting visual representations according to linguistic or quantitative logics (for example as graphs) which enhance their status by associating them with a quantitative ethos. Digitalisation of scientific data, as analysed elsewhere in this thesis, is associated with the quantification of the visual, constructed as a form that supports a graphical representation of quantities. As I will show in this chapter, without the indication of scales and statistical significance of measurements, representations in functional imaging are at best ‘pretty pictures’. Discourse has become
calculation in the digital age, the word subsumed to number, quantitation preceding explanation.

Such hierarchies have a history and cultural logic, which has been pursued by a number of disciplines—philosophy, art history, sociology and anthropology, etc. Two threads of this history will be most relevant here: studies which have shown an association of disciplinary identity to ways of knowing, and those which have addressed the place of visual knowledge in relation to other ways of knowing. I am not so much interested in the ‘epistemological essence of knowing’, but rather in the ways these representations are used to mark the work of brain mappers and carry their knowledge claims.

Some scholars in science studies have demonstrated that the notion of “epistemic cultures” can be used to characterise forms of research (Knorr Cetina, 1999; Loewy, 1992). Other have shown the need for groups to maintain an identity in order to have their particular contributions recognised, and to claim scientific or professional authority—with practical consequences for obtaining resources. Such an identity can be built through demarcation work, by using rhetorical strategies (Derksen, 1997). Demarcations must yield more than simply the possibility of having an enclosed circle in which to develop scientific theories—it must also create a ‘demand’ for a particular kind of knowledge or expertise (Derkseen, 1999). In the case at hand, the format of the knowledge claims of researchers will be shown to be reconfigured in particular contexts, to better create such a demand. The boundary objects used for this purpose can be problematic in and of themselves. Derksen has shown that common-sensical notions used by psychologists are considered to pose particular difficulties, because they belong at once to the rhetorical set of tools used to reach out to a lay audience and to the domain of investigation of psychologists. The use of representations will be also be shown to be problematic in that these can also be understood by a lay public while forming the basis of scientific investigations. In both cases, the immediacy of understanding, the very effectiveness of the medium that conveys the expert’s knowledge to non-experts, challenges the expert’s status by virtue of seeming to make this knowledge directly accessible.

Some researchers have focused more specifically on the links between professional aspirations of groups using visual evidence. Galison’s study of two contrasting traditions in microphysics identifies a ‘logic’ and an ‘image’ tradition, and on the basis of the instrumentation developed by each, traces the contrasting epistemics with which knowledge claims are made and transmitted. The two traditions merge with the

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94 Sargent (1998) signals that philosophers have recently begun to consider that scientific work might also include non-linguistic elements in the cognitive and communicative activities of researchers (See also Gooding... She also explores how brain mapping might be a fruitful terrain for investigating such questions.

95 But see Lynch (1991).

96 Researchers using imaging very occasionally reflect on this topic, and occasionally mention Crease (1993) or some of the work by Tufte (1983, 1990) to point to issues in representational strategies, but they do not integrate these insights into their practices.

97 Galison looks at the two competing traditions in instrument-making in modern physics: ‘images’ are mimetic, purport to preserve the form of things as they occur in the world, and are ‘homomorphic’, while
digitalisation of instrumentation, which allows both a quantitative and imagistic approach to be combined. Galison’s work highlights how these traditions endure, through three levels of continuity: pedagogical (‘family trees’ of students), technical (day-to-day skills), and epistemic or demonstrative (ways of arguing, of demonstrating). The last dynamic, claim-making, will be the focus here.

Another point from Galison which is relevant to this discussion is the privileging of the ‘image’ tradition’s results in popularisation (of discoveries of new particles, etc.). Images are rhetorically powerful (in a Latourian sense) to carry the existence of new phenomena into new realms (Galison, 1997). I have discussed elsewhere how this is also the case for brain imaging, through reliance on an understanding of the visual which is based on photographic realism. Here, with regards to both the scientific community and ‘the public’, I will argue that ‘images’ are not only powerful, but also dangerous, because of their role as boundary-objects which place them at different points in the hierarchy described above.

Pasveer has also analysed the creation of a ‘representational practice’, one involving x-rays, but also many other nodes in a network (Pasveer, 1992). Her description of complex dynamics needed to make something count as evidence highlights how representational strategies are best understood as part of networks, where meaning-making occurs in relation to other types of evidence, rather than in relation to ‘the world’ (Pasveer, 1992). The rise of new objects of knowledge as the result of mutual construction of technologies, professions and representations will also be shown here, especially in the second part of the chapter. Insofar as the notion of a hierarchy of evidence is invoked by functional imagers, however, this analysis will stress contrasts with existing practices and groups rather than the construction of new objects (but see chapters 2, 3, and 5).

From a cultural studies perspective, Cartwright has analysed the use of visual empiricism by neurologists in America in the first half of the 20th century. The professional anxiety of neurologists, and their recourse to a visual approach of surface classifications, can be linked to the growing threat posed to their professional domain by psychoanalysis, and its aural empiricism of deep phenomena. The production of a new gaze for beholding bodily surfaces through the use of cinematic technologies can be understood as an attempt to reinforce the traditional neurological approach of visual classifications. These classificatory tools did not succeed, however, and remained marginal (Cartwright, 1995). Here, the use of visual evidence will be discussed not as a defensive move but as an entrepreneurial one, where functional imaging tries to establish its domain of competence among existing disciplines. This brief review therefore points

‘logic’ uses electronic counters to make statistical arguments for the existence of a particle or effect and are ‘homologous’ representations (Galison, 1997).

This hybrid state of physics instrumentation (electronic counters used to produce visualizations) is very much the starting point of PET brain imaging technology (around 1975).

See Beaulieu (2000) for a discussion of the popularisation of imaging.
to the possibility of analysing professional distinctions (and the aspirations of emerging disciplines) in terms of ways they promote their knowledge claims.

Other researchers who have considered functional imaging have also noted the importance of representations in the functional imaging community:

“Yet, the cross-point is a picture. For the runners the picture is an end. For the users the picture is a starter. The more accessible the meaning of the picture is, the most powerful are the discourses and actions generated on its basis. Therefore, the unifying interest of both runners and users is to improve the quality and the veracity of the picture, since the existence and the welfare of this hybrid world depends on the promotion of the high status of this picture among the profession and the public at large.” (Anguelov, 1994)

My analysis will demonstrate the contrasting definitions of what constitutes "quality and veracity" in the various disciplines in which functional imaging is used. This makes the demarcation work, on which the existence and welfare of this hybrid world depends, extremely complex.

What Representations Can and Cannot Do

Researchers involved in brain imaging have a complex understanding of the representations they use. They strive to make their brain scans, maps and atlases quantitative and therefore scientific, but also try to hold on to some imagistic qualities of these representations, namely, the evocation of spatiality and the layering of data. The understanding of representations in the functional imaging community is characterised by a strong division between two possible functions of images, negative and positive. The first of these functions is explicitly denied to the image, and thereby defines it negatively: images do not form the empirical basis of functional imaging. Within this negation of the image, two main types of tropes arise, each positioning functional imaging in relation to scientific ideals and demarcating functional imaging from less scientific endeavours. The first redefines the image as a representation of quantitation, and aims to establish the scientific foundations of the research pursued ("they're not pictures, they're statistical maps"). Related to this theme is the constitution of the research as independent from the imaging technologies used (not pretty pictures). A second group of tropes distantiates the work done by researchers from the clinical applications of (PET) imaging ("this is not a radiological science") and the nuclear medicine origin of PET. A second, communicative function, is discussed later.
Trope 1: “They’re not pictures, they’re statistical maps. So you’re showing hard evidence.”

The quotations below are taken from interviews with senior researchers. Associating things visual with functional imaging angers them:

“Dumit: Do you have a favourite image?
T-P: No!
Dumit: I was curious. Do you consider yourself a visual person?
T-P: (pauses) Probably yes, but I have to think about that.
Dumit: right.
T-P: Let me put it this way. If I look at an image or at numbers, I am more concerned with what it represents than how it represents it. I don’t know if that answers your question, but I am trying it (Dumit, 1995).”

AB: Now PET is a visual technology. what do you think the promise of that is--
Researcher: PET is a visual technology?
AB: Huh. an imaging technology--
Res: Why do you call it a visual technology? why do you want to associate vision with imaging?
AB: Hum [pause]. I’m afraid I wasn’t neutral enough. PET results take a visual form. Do you think that is an important aspect?
Res: No. I don’t! Actually it’s sort of a radiologic misnomer.

Pacifying work on the part of the interviewer is needed to maintain dialogue between clashing conceptions of what is going on in functional imaging. The abundance of representations in neuroscientific contexts which overwhelms the neophyte,\(^\text{100}\) clashes with the conceptions of researchers that they are involved in making measurements in the brain, not obtaining images of it. An interesting exception I encountered to this attitude among researchers had to do with a once-off experience, often marking pioneering moments. In such cases, the researchers acknowledged the significance of seeing, when the visualisation enabled by the technology led to a kind of witnessing. For example,

[the visual] had an initial impact. it was extraordinarily exciting to see things that had never been seen before. I remember several occasions at the Hammersmith, where we saw things that no one had ever seen before. Like the substantia nigra

\(^{100}\) I recall jotting down in my notes that I was seeing more images at my first brain conference than at any film or art history lecture I had ever attended. This contrast between the empirical basis and the mode of expression can also be explained at least partly by the association of hierarchies of ways of knowing—art historians seek to heighten their insight into art through linguistic expression of their visual understanding, while brain imagers, having a stronger empirical basis, relatively speaking, can afford to make their expression visual. I am also a participant in this—the first version [and now final] of this chapter contains no illustrations. Gould notes in passing this distinction in rhetorical style of scientists and humanists (Gould, 1998).
working. So there is an impact, which I guess is the same as the impact of looking through a telescope and seeing something that no one has ever seen before, the impact of the moment when looking at a comet, which is extraordinarily exciting to see... (Senior Researcher, trained as psychologist).

The sensory is associated with experience, the moment of discovery or first observation, and not with reasoning. Here is another example, particularly interesting for its use of an aesthetic vocabulary:

"Nothing can quite describe our excitement during our first scans in seeing how specific the brain’s activity was and how beautifully it adapted to the requirements of the task (Posner and Raichle, 1995)."

A sense of wonder is associated with seeing when related to a particular event. Here, a representation again marks discovery at a point in time:

‘See that?’ gestures Dr. Michael E. Phelps, the Jennifer Jones Simon Chair in Biophysics, pointing to a framed cover of a 1982 edition of *Science* on his office wall. ‘That was the first time anyone has ever shown functional mapping of the brain in living people.’
(http://www.bruin.ucla.edu/feature/challenge/maptext.htm).

But ordinary day-to-day practice of scientific investigation does not fall under such a category. Seeing is not the ordinary technique of investigation; one does not do this work because one is visually oriented.

Researchers insist on the fact that they are not involved in observation, but in measurement work. Speaking of representations in PET scanning, this researcher explains that “they’re deceiving to some extent because if there’s no hard statistics underneath, then they’re just pretty pictures. (Senior Researcher, trained as neuroscientist)”. The data of research is described as quantitative: the work is done using “a coloured representation of a set of statistical values” (Junior researcher, trained as physician). Explanations of representations focus on the measurement work involved in making scans:

“As far as I’m concerned, we are doing serious quantitative systems neuroscience. We are very conscious that we are doing 3 and 4 dimensional data analysis. The fact that the data is representable in an appealing visual form is extra... (Senior researcher, trained as physicist).”

The visual in the quotation above is described as almost accidental, an emergent property of the quantitative data. The data are measurements of phenomena, and they define complex phenomena in a way that visualisation could not achieve. Here, a researcher contrasts visualisation work, where a representation used by a surgeon is based on a
correspondence to the brain of the patient, and an activation study, where the referent is a set of complex measurements:

"But for. I don’t know, cognitive activation paradigm, you want to measure what structure is being used. And there, because of the statistics involved, because of the noise involved, it’s a quantification problem. Some of the things they’re looking at now are so subtle that [they’re] trying to figure out whether it’s real or whether it’s not (Researcher, trained as computer scientist)."

An anatomical reality can be apprehended visually, but complex psychological phenomena must be measured and rendered quantitatively. The instrument’s use and the understanding of the representation are aligned, integrated in a quantitative mode. This insistence on the quantitative is one of the strategies that prevents the “proliferation of meaning”, prized by artists and not by scientists (Bastide, 1990), narrowing the possibility of interpretations that can be made of the results. Although the representation can be altered, made to look better, its referent is solidly quantitative:

"...particularly now with image editing and enhancing, you can manipulate images, and ultimately, one should be able to track everything back down to tables of numbers which are locations of activations in Talairach space, it’s the sort of concept that underneath a glossy exterior, there’s a strong skeleton, that refers back to [inaud] that is what gives some coherence and credibility...(Senior researcher, trained as physicist)."

Joe Dumit (1997) labels this reliance monosemy, a quality of the information provided by scans, but more generally it is also one of the main features built into the neuroscientific understanding and production of representations.

The rejection of the visual and the embracing of the quantitative referent involved is often done in the same breath, evoking progress:

"but I think that for a field to grow up--and everybody thinks the same, I don’t think I’m giving you views that are different from anybody else, in the best places. I don’t think I’m putting forward views that are the slightest bit heretical--it becomes important that it become quantitative, science doesn’t just deal with pictures it deals with counting things, graphing things, plotting things. (Senior Researcher, trained as psychologist)"

These arguments for the quantitative nature of data and against the visual component can be seen as a positioning of functional imaging as a scientific endeavour. The representations used are renderings of quantitative measurements, and stand for complex phenomena. The researchers therefore align their empirical basis, the scans and maps they use, with a quantitative and experimental approach, rather than a visual and observational one. Brain mappers perform experiments where brain functions are variables, where responses are tested statistically, and group data carefully analysed. In their
understanding, a ‘visual’ label reduces this work to ‘observation’. Such observations might be useful for the neurosurgeon, who must plan an intervention—but not for the scientist.

Even within research activities using PET, there is a hierarchy from more to less quantitative, depending on the way measurements are made: “There are conflicts between those who use it qualitatively and superficially and those who use it analytically, by their nature.” (Phelps in Dumit, 1995). This researcher then goes on to contrast various types of research, and the likely reaction of neurochemists (from the highly quantitative end) to clinical research:

“I don’t like that, you don’t know what you are talking about. What are the units of your data, depression on this axis versus colour on this axis?” So there are a lot of factions within PET, because it does go from basic chemists and biologists to clinical investigators, and their criteria of an experiment is quite different (quoted in Dumit, 1995).

These differences of criteria of an experiment can be traced in my analysis, not only within different groups using PET but also with the neighbouring groups of researchers. A frequently recurring expression (already encountered above) in discussions of representation is the phrase “pretty pictures”.

[speaking of the visual, the interviewee has just explained how it is significant for communicating with the public]

AB: But it’s also valued among scientists.

Int.: Within the field we know what we are doing. I’m talking about one removed. If you’re not in the brain imaging field, it’s very easy to dismiss brain imaging as pseudo-science. Those of us in the field know what those pictures, which are so pretty, underlie, what they represent. I’m not saying that is not something that is usable scientifically ....(Senior researcher, trained as physicist).

The description of functional imaging work as making “pretty pictures” invokes again an accusation of lack of scientific purpose, through associations with a non-scientific, visual and ‘photographic’ approach. This pejorative description is often heard coming from psychologists who critique the way ‘function’ is studied. Making pretty pictures of the brain is at best observational, and not the scientific study of function through the complex experimental designs prized by psychologists.\(^1\)

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\(^1\) This complex experimental design especially focuses on manipulating tasks so that ‘functions’/processing stages/operations can be distinguished. Cognitive psychologists focus on very specific components of tasks, for example distinguishing visually presented animals from visually presented tools. Functional imaging has investigated functions at a less specific level, with early experiments distinguishing ‘cognitive’ from ‘visual’ activations for example. More recent work has produced more sophisticated activation paradigms, but the degree of specificity in tasks performed in still not as great as in cognitive psychology. Cognitive psychologists also focus on measures of time and error/accuracy of responses. This contrasts of measurements in time and space will be further discussed in the second part of the chapter.
The phrase, “pretty picture”, has links to the previous trope, since it points to the sensitive issue of (lack of) scientific sophistication. It also relates to the next trope, since it defines brain mapping work as dependent on the technologies used, invoking the passive photographer whose apparatus does the work. The prominence of technology in functional imaging is difficult to overcome: a PET scanner and cyclotron cost up to 7-10 million $US, and around 1500$US per scan. This is especially true given the low tech context in which much of this work is done. Functional imaging is ‘little big science’. whereas psychology and neurology are not highly technologically-dependent fields of research. This over-identification with the technologies they use is countered in general ways by functional imagers by insisting that functional imaging has moved into mainstream neuroscience, and sometimes seeming to avoid `imaging’ in describing their work. More specific strategies will be discussed below.

In terms of the status of representations, therefore, functional imagers argue for a quantitative definition of their representations. Representations, when understood as part of an imagistic register, are only accepted as part of moments of discovery. Otherwise, a discussion in visual terms of the representations used by imagers is considered a lack of understanding of the approach and phenomena these researchers are investigating. Sometimes, such descriptions are precisely aimed at questioning the status of the research (just ‘pretty pictures’). But, for brain mappers, the proper understanding of functional imaging is to see it as an experimental strategy that measures and explores the brain quantitatively, not one that visualises it. Interestingly, researchers also connect an explanation for the use of “the visual” or visualisation to the complexity of their quantitative data—their data is the result of complex quantitative relationship that can best be rendered visually.

If representations are quantitative, the proper way of understanding them must also involve a quantitative rationality. This is the basis of the second trope.

**Trope 2** “I have no truck with people who look at images and interpret them.”

This trope also negates the visual, but it is directed at a different kind of demarcation of these scientists’ work, setting researchers apart from the clinic. The clinicians are image-oriented, to the researcher’s chagrin. Measurements in quantitative form should be enough to understand the scans, but they are not:

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102 There are other parallels to be drawn with big science. In the eighties, there were discussions about setting up a large brain centre, CERN style, in Europe.
103 Arguments about the need to distance the research endeavour from the technological means also arose in discussions around the setting up of the Organization for Human Brain Mapping. The setting up of a professional organization based on the common use of technologies was resisted as unnecessary or even a dead end. A loose association was chosen over a strong professional organization.
In our clinical work, we provide a list of all brain areas, the metabolic rate for that patient in that area, and the normal range for that area based on our files. And whether that person is plus or minus two standards deviations of the normal range for each area. We also provide the colour images because the physicians want it, but we would be happy on our clinical reports just supplying the numerical information (quoted in Dumit, 1995).

Clinicians therefore desire a beautiful image of the brain, a desire Dumit has analysed as a culturally-based longing for insight into what subtends our personhood. But the clinician’s desire is the researcher’s aberration. It reduces the work to scan-making, a technicians’ occupation. A quotation above indicates that to link PET and vision is a “radiologic misnomer”. This opposition to radiology recurred several times in interviews:

“Well, I think that in the field that I’m involved in, which is functional mapping, we have maintained the tradition of quantitation, even if it’s relative quantitative or statistical level quantitative, and SPM has been critical to that. So there’s no question we would simply inspect images in a radiological sense to make diagnosis or conclusions. That’s just not in the ethos at all of what we do and it’s never been in my ethos (Senior researcher, trained as physician).”

“And they [spm’s] do not signify and do not require the sort of interpretation that a standard radiograph might (Senior researcher, trained as physician)”

A number of threads can be followed to explain these moves to distantiation from the clinic. First, it is a distinction that relates to the history of the development of these scanners. PET scanners were developed in nuclear medical settings (see chapter 2) and while a number of potential uses were suggested, the most enthusiastically pursued was that aimed at tumour detection. But even within the early research on cerebral blood flow, there were those working in the tradition of auto-radiography and those oriented to nuclear medicine. At this point, it seems that the clinical and research distinctions were already articulated along the lines of image versus number. In this passage, one of the

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104 See Dumit (1994) in which he analyses the cultural longing for and implications of imaging the brain. In relation to PET, some of the early goals in nuclear medicine were to develop a tool that would compete with x-ray CT, for example by allowing imaging of structure of organs that could not be detected by x-ray (Wagner, 1992). Raichle recounts the efforts as trying to regain ground lost to CT: “Nuclear medicine brain scans, which had been a staple of the practice of nuclear medicine, were quickly replaced by x-ray CT (Raichle, 1996).” There was also a tension between the clinically oriented imagers and those who wanted to do autoradiography in humans with it. Raichle argues the right course was to hold off from clinical applications, because it did not provide anatomical data that was already understood clinically, but rather measurements that were not... The link between the measurement of brain blood flow and brain activity was not a significant part of the PET agenda until about 1984, and it became a measurement of ‘cognitive’ processes a few years later. Mature PET (in a technological sense) had already been developed for ten years at that point.
pioneers of the methods on which PET is based. Louis Sokoloff. was said to be uninterested in detection by imaging. He reaffirmed the alignment of science and measurement, citing an aphorism by Lord Kelvin that hangs on his office wall, "When you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind (Kennedy, 1991)." The move towards complex quantitative analysis processes is also considered part of the development of functional imaging research.

The marked contrast between research and clinical goals of diagnosis/research is also expressed in debates about the very way in which these representations are to be understood. In the eighties, a debate around the interpretation of PET scans was fought out, between the quantitative and visual approach to PET scans, at a workshop on PET analysis and in journals. One side claimed that clinical PET can produce representations that can be understood visually: researcher insisted on a quantitative measurement and a quantitative evaluation. In this debate, PET scans were seen as highly processed data— involving normalisations, statistical tests and the use of complex models. Clinicians argued that certain elements of this process might be bypassed without compromising the validity of scans and with the benefit of increasing the clinical usefulness of PET. One commentator described the production of PET scans in its (original) research context as a chain of events, which, while theoretically improving the data, might not have clinical, biological relevance (Di Chiro, G. and RA Brooks, 1988).

The researcher's analytic approach was not welcomed in the clinic as impractical, possibly unnecessary, and often unfeasible. One reviewer summarised the clinical side of the debate as follows:

"too much emphasis has been placed on sophisticated statistical analyses and not enough on common sense. If no difference is seen visually or graphically, then it either does not exist or it is too small, compared with methodologic error, to have great significance (Aine, 1995)."

Furthermore, even when no objections were raised against quantification as being overly complex, the visual appearance was argued to be an even better basis for judgement than quantitative indications (rates described in tables and lists):

"The visual appearance of the tumour is a far better guide to tumour grade than the absolute metabolic rate (Di Chiro and Brooks, 1988)."

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106 Husband of nurse and aircraft pilot Betty Kaiser, Louis Sokoloff worked with Kety and Schmidt at University of Pennsylvania, and later at the NIMH. He is said to have inspired the 'fathers' of PET.  
107 A stream of STS research analyses the professionalisation of vision, (seeing as a learned activity and not as a self-evident, biologically-determined sensory activity), and the codification of the understanding of visual evidence. Vision is shown to be the result of various social, interactive processes and not a given perceptual attribute. This last body of scholarship includes both analyses of the historical formation of vision (Crary, 1991; Cartwright, 1995; Pasveer, 1992; Kember, 1991) and of professionalisation (See footnote 13).
Another way of understanding the importance of the distinctions researchers make between visual evaluation and a quantitative approach is to look at a proposal for crossing this boundary. Writing in the *Journal of Neuropsychiatry and Clinical Neuroscience*, clinical researcher Andreassen proposes going from a ‘clinical’ to ‘research-oriented’ use of imaging. While “many of these techniques have been developed and marketed as clinical tools to permit physicians to look and render a judgement as to whether a structure or functions is normal or abnormal,” the clinical tools can be adapted to serve research purposes (Andreassen et al. 1992). The transformation consists in retrieving the quantitative:

“Essentially, the challenge of image analysis is to convert information originally meant for visual gestalt processing into a quantitative and mathematical tool that provides precise estimates of structure size, shape, volume, or physiological activity (Andreassen et al. 1992).”

Andreassen’s lab offers a number of tools for this purpose. Note that not only does the understanding changes (from visual gestalt) but also that ‘precision’ is to be gained and discrete elements to be measured (size, volume, etc.) rather than an understanding of the whole—a gestalt image, presumably of a normal or abnormal brain. While the focus here is on the main quantitative/visual distinctions, a number of features of imaging could also be shown to contrast between lab and clinic: the use of colour for example. To go from a clinical image to research data, one must shift from looking to measuring, from visual understanding to quantifying.

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108 See note 107. The clinical gaze is not itself simple, unproblematic. There are ‘rules’ for visual understanding, which are also embedded in technologies and histories.

109 Andreassen notes that observer intervention is sometimes necessary in using some of these tools, but she also redlines seeing in mechanistic terms. The observer is also described as ‘technically’ incorporated into the machine in another article on an analysis tool developed by the Evans group: “The methods described here seek to take advantage of the pattern-recognition qualities of the human eye with noisy, low-contrast anatomical images while adhering to a pre-defined framework for anatomical mapping. (Evans et al. 1988).” As these notions are set in a context where technologies of vision grow in importance, these relations are partly reconfigured, so that perception is best replaced by automated tools which never fire, which feed reason only the most rational of percepts, images of numbers.

110 Besides colour, there are many other ‘conventions’ for these representations—such as ‘view’, slicing, or the use of shading, etc. The development of conventions for the use of colour in medical imaging would deserve a book-length study. (See Keyes (1997) for a sketch of some of the issues, especially pages 207-8). Robert Savoy, of Massachusetts General Hospital, explained in a lecture at the human brain mapping conference 1996 that the use of colour for medical imaging is not allowed in the US, because it turns quantitative differences into “categorical variables.” Quality and quantity clash. The ‘rainbow question’ has often been posed to me, most succintly by a historian of psychology and things visual (‘how did the brain get its colours?’). Yet, it is not an issue that seems to be of interest to the scientists—the colours are ‘simply’ from ‘the packages’, etc. I would suggest, however, that the use of grey for structure is part of the x-ray esthetic, (which may have developed based on the kinds of chemicals that were used to coat plates) and the colours as ‘the juice’, the activations. I have also observed that other spectrums, like ‘hot metal’ are also used chosen for activations over grey schemes, though they retain the element of gradated colours.
Those 'who look at images an interpret them' are therefore clinicians using PET. They are those who have different (or less) technological support, a different expertise and goals that clearly differ, though they use some of the same technology. The arguments about the visual/quantitative understanding of these representations express the depth of these differences. The debate about quantitation versus visual inspection seems to have subsided in the nineties, as research-oriented journals developed, on the one hand, and separate meetings were held.

The lab/clinic relations within the institutions where I did fieldwork were mirrored in the ways these distinctions were made and the ease with which lab/clinic boundaries were crossed (see Annex 1). In the institution where there was little interaction with clinical work, the distinction was firm ("I have no truck...") while at the second lab, the opinions were expressed in more relative terms ('different tools for different purposes'). Where relations with the hospital were problematic, the analysis software was strongly directed to a quantitation approach; the documentation accompanying the software explicitly stated that is was not meant to be a bio-medical imaging package. The programming language used to write this software is also much better suited at handling matrices than images, thereby incorporating the distinctive research orientation into the tools of the research centre. At the second centre, where researchers were much more involved in clinical work, the analysis software was suitable for visualisation of individual patient's scans, and biomedical visualisation work was considered useful. A work station capable of displaying this data could also be wheeled into the O.R. to allow the consultation of mapping data during surgery.

A further reason for this boundary work may be found in the precarious position PET has occupied as a clinical tool. As a very expensive technology, PET's clinical presence has been particularly controversial in the Western economic context of the eighties (Kevles, 1997). But the costs have not been the only challenge to PET's clinical acceptance. Technically, the need for an on-site cyclotron makes the use of PET a big enterprise even for academic/research oriented hospitals (Frick et al., 1992). The regulation of tracer production has also been perceived as threatening the wider distribution of PET scanners (Coleman, 1993). At regular intervals for the past 3 decades, PET has been said to be on the cusp of becoming clinical or of losing what little foothold it had acquired and has seen its clinical efficacy problematised or downright challenged.

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111 With the following exception: Raichle speaks of looking at 'raw data', which can be useful to an experienced user—rather than always looking at thresholded images (significance-tested, normalised data.) In this role, scans are "exploratory pictures" (Galison, 1997).

112 The development of neuroscientific tools that can 'use' images, (scans as visual representation), such as the probabilistic atlas, is a deliberate accommodation of the clinical form of scans. This is done in the hope of enabling more widespread use of atlases.

113 Especially in the US, the regulation of the radioactive tracers requiring them to be receive FDA approval as though they were 'drugs' has been bemoaned as holding back the spread of the technology (Coleman, 1993).

(Powers et al. 1991; Volkow and Tancredi, 1986). Maintaining associations with clinical PET, which is challenged in terms of safety, clinical usefulness and economic liability, is therefore not appealing to research groups.

Claims to scientific status, and degrees of greater scientific legitimacy can therefore be understood by the rejection of definitions of representations that focus too closely on 'the visual', which is not scientific because not quantitative, which belongs in the clinic because of the understanding involved (judgement), and which too closely ties the work to imaging technologies and observation. These discussions of the role that representations do not play are therefore indicative of the ideals which functional imaging is pursuing. Furthermore, they also show how these ideals are embedded in the kind of empirical basis being considered.

Rhetorical Representations: When is a Picture Worth a Thousand Words?

A second, positive role is readily granted to representations, however, insofar as they function as tools for communication and not as an empirical basis, or style of evaluation. Representations are thus praised for their directness, and synthetic power, which imagers see as legitimately deployable in communications with colleagues or the public. Representations are especially suited for communicating results:

"The most profound use of computers in mapping is in the field of visualisation. Computerised visualisation of data that has been converted into a cartographic image of a spatial domain best communicates the meaning of quantitative information. Some people can see in their mind's eye the beauty and structure in mathematical or statistical relationships, but most require a visual representation to best appreciate these dependencies... (Toga and Mazzotti, 1996)."

These arguments not only limit the meaning that such representations can have (and prevent the undesirable effects described above) but they also reinforce the first trope, regarding the complexity of the data. Not only is the empirical basis of functional imaging quantitative, but the very complexity of the data calls for the visual presentation of results (visualisation).

"Wagner: [these studies in four dimensions] can only be abstracted and displayed in a meaningful way in the form of images. Otherwise there are too many numbers. Your brain can't really handle more that a couple of variables at one time if they are quantitative, so you have to have abstractions. And images are a very, very nice way of abstracting quantification (Dumit, 1995). "

Note the choice of an analytic, rational vocabulary—these are abstractions not pictures. Besides limiting its function to communication, researchers occasionally also provide an explanation for the efficacy of visualisation—an explanation grounded in the cognitive systems of the brain they study. The visual system is the sensory modality with the
broadest bandwidth, so the argument goes, therefore best suited to conveying complex data to the brain. By 'totalling the observer'\textsuperscript{115}, the scientific process is extended by incorporating the physicality of the human body into the apparatus of scientific reason. The use of vision in relation to representations is rational, its efficiency explainable.

But the danger of improper understanding still lurks; credentials are necessary to be properly visual and scientific:

"But then there are people who believe it's silly to show an SPM because you need to be an expert to understand an SPM, like showing an x-ray to a radiographer versus to a midwife who has no experience of chest x-rays. You need to get expert, and it can be dangerous to give too much information which may be interpreted in an intuitive manner rather than knowing exactly what is going on... But that is not my problem, my problem is to present data with great integrity and greatest validity... (Senior researcher, trained as a psychiatrist)"

"Let's take an SPM. To the uninitiated, they will see a picture as an activity in the brain and at some level they will see that as the activity and they will forget that it has to be taken into account that that is not the activity, that is a coloured representation of a set of statistical values. And those values have been smoothed spatially, and in time, in the case of fMRI. They've been warped. They've been realigned. They've been through all kinds of crunch, and in setting out to simplify, the picture can to some extent deceive. (Junior Researcher, trained as physician)."

To see a picture as transparent is not an appropriate way of seeing, so that even when quantified, the measurements must be understood in terms of their production, not simply in terms of the phenomena they represent. This responsibility to see properly echoes what I evoked as one of the enduring aspects of modern concepts of scientific ideals earlier: reason's duty to monitor the senses. This notion surfaces in moral terms, where, in the face of the development of more and more imaging technologies, scientists must bear the responsibility of proper scientific knowing and not be deceived by the transparency of images (Crease, 1993). An image, the argument goes, can fool you into thinking you understand an object in a way a graph or measurement wouldn't. This aligns rationality, proper understanding and moral responsibility as one mode of dealing with images, and intuitive understanding, uncertain knowledge and seduction as another.\textsuperscript{116}

\textsuperscript{115} The phrase is from John Tagg (1989). See also Jonathan Crary (1992) and Sarah Kember (1998) for analyses of displacements of the observer in relation to technologies of photography and digital imaging.

\textsuperscript{116} For example: "You have to be careful not to be seduced by the images. You have to understand, from the scientific point of view, that the paper you write, you are not writing for Psychology Today. You are not writing for Newsweek, you are writing for the journals. You have to have statistics, and I have often said that, as fancy and compelling as the PET scans is, you still need a good solid research design, with an adequate number of subjects and the right statistics (quoted in Dumit 1995)."
Yet, in other settings, it is precisely the seduction of the viewer through an intuitive understanding of representations which enables functional imagers to communicate effectively. Researchers acknowledge the efficiency of representations in drawing the attention of the public to their work, though the lay public will understand them differently. The impact on the public can be great:

"No, the thing that’s handy about it though, is that because you can make pretty pictures it’s easy to get across some of the information to a lay public. Which in times when science is being sliced and diced, it’s always nice to be able to have science published in a lay journal—even if they screw it up a bit. It’s, I mean, an energy physicist would have a very hard time trying to justify why they need more money, why they need millions of dollars more to go identify another subatomic particle, and we can show pictures of the brain lighting up or not lighting up, and some activation paradigms, and it’s easy for someone to understand. They can see the importance, as opposed for instance to finding some subatomic particles. (Junior researcher, trained as computer scientist)

Arguably, physicists also find means to communicate with the lay public about their field—and this may even be through their own “pretty pictures” (c.f. Galison). But such effects, which scientists attribute to the images, are not trivial. What I wish to highlight here are the demarcations that researchers themselves make in relation to representations. Though the effect may be desirable, representations outside the proper scientific and professional settings will not have a rational impact:

"You can put out all the words in the world, but a picture is very powerful in communicating the information. So it is a medium that on the one hand allows you to communicate more easily with the public but on the other you can start imagining things from this image that aren’t real (Phelps in Dumit, 1995)."

"I think between scientists, they are less easily impressed by the picture…. I mean, it’s a quick reference point, but then you want to know a lot more about it whereas Joe Public would look at it and goes: oooooh, this is what the brain does (Junior researcher, trained as physician)."

11 It has been suggested that PET played a role in convincing a ‘chairman’ to support research:

"You are interested in anecdotes. Some time ago there was a meeting here, a relatively small meeting. Including Mr McDonnell, James McDonnell, who was a founder and a chairman of the board of McDonnell Aircraft. He was very much interested in the human mind. His hero was Penfield. He came to this university trying to convince people to get interested in the human mind, and, among other things, to get interested in parapsychology. Not many people in this institution are interested in parapsychology. So finally I think Mr McDonnell was convinced by a group of people. I was one of them, that perhaps PET is close to what he is interested in. And he helped out financially, and is still helping out through his McDonnell Foundation for the Neurosciences, some of the PET activities (Ter-Pogossian in Dumit, 1995)"
The image speaks for itself, but not in quite the same way to everyone. One of the consequences of this dual register around representations is that it allows neuroscientists to have it both ways: to make claims with scientific integrity while providing visually exciting materials for the public to understand 'intuitively'—and because of this understanding, gather further support for research. Lynch has observed a similar duality in the work of astronomers, also working a digital context, who produce both popular 'pretty pictures' and scientifically useful representations. The pretty pictures are used for rhetorical purposes, invoking an optical truth118 (Lynch, 1991). Lynch analyses this as a purposeful acting as a “community of the wise, sharing a secret understanding of non-apparent qualities while putting on a front for the sake of prevailing standards of taste and decorum (Lynch, 1991)." This is only part of the dynamic of the use of representations, however, and there are other (pro-active) aspects to the scientists use of representations for popularisation. Scientists are also conversant in the register of photographic realism and produce, when necessary, accounts based on such an understanding of these representations.119

But the possibility of working both crowds has certain limits—the intuitive is not scientific and therefore dangerous. Other scientists also monitor the boundary between lay and scientific discourses, and functional imagers are aware of the possibility of a backlash:

Uncritically, everybody gets excited about imaging. It's a double-edged sword, because it's nice to get into the media but also sometimes tends to be denigrated by other scientists in other scientific domains as glitz and showboating rather than serious science. As far as I'm concerned we are doing serious quantitative systems neuroscience. We are very conscious that we are doing 3 and 4 dimensional data analysis. The fact that the data is actually representable in an appealing visual form is extra. (Senior Researcher, trained as physicist)

The restraint of scientists is therefore not only a question of being silent about the difficulties and contingencies of digital imaging, but researchers must also observe a certain restraint in presenting their work in non-scientific terms. This is not platonic rhetoric of techno-sceptics to denounce visual corruption, to use Staffords’ phrase,120 but rather gate-keeping between the rationality of the scientific world and the intuitive reasoning of the public. When representations which scientists believe invoke intuitive, non-scientific modes of understanding are used, the threat is all the more powerful. This may add a further layer to Lynch's programme of understanding optimism in terms of “a set of instructions for performing actions in accord with the various optical knowledge-production machines; a disciplinary compliance on the part of the subjects in those

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118 Part of the optical register is 'photographic realism'. The photographic effect, however, is arguably not intuitive, however, but rather depends on the viewer's familiarity with the conventions of photography. This is an understanding which to the Western observer has been exposed for 150 years (Mitchell, 1994).

119 They know how to use a pictorial vocabulary, and can talk about seeing the brain light up, looking at the brain in action, taking snapshots etc.


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systems (Lynch, 1991)." This dynamic of backlash reinforces the scenarios of compliance with rationality (which is not visual) and the maintenance of the boundary between the scientific and the popular. The epistemes of functional imagers cannot include the purely imagistic, without renouncing claims to be pursuing quantitative, scientific experiments.

Researchers recast the discussion of representations from visual to quantitative terms to insist on the scientific character of their research, and to distinguish their work from other uses of representations, for clinical or popularisation purposes. This analysis shows that a number of factors affects the discussions of representations in a given scientific practice: measurements, location of research, technologies used, clinical versus research goals, scientific and lay understandings. While interesting in itself for what it tells about a particular scientific practice, and the yield that an analysis of negative statements can provide, I would like to press the issue of the use of representations one step further. These researchers are not entirely iconoclastic in that they do accept that images play a role, but they do fear too great a reliance on the icon—a seduction of the senses and the neglect of the greater truth that lies beyond representations. They are also wary of the accusation of being occupied with the making of pretty pictures, that come from other scientists. Yet, these representations endure. The argument that they are valuable as tools for rhetorical purposes does not entirely explain their continued presence. They are used in contexts that might not be primarily defined as communicative, for example, in data collection or data analysis. I therefore want to analyse in the second part of this chapter what further role these representations might play. I will argue that while an epistemic role is denied to representations, their use does make the contributions to the study of the brain specific to functional imaging. These claims to particular insight are based in the spatiality of the data. But this spatiality is achieved by using some of the conventions of anatomy, a domain where the pictorial and observational organisation of the work prevail—the very features from which functional imagers try to distantiate themselves.

**What You Can Do With Images, That Others Can’t**

Below is an excerpt from an explanation of the goals of functional imaging, where a strict definition of the epistemological basis of imaging is used by this researcher. This explanation was offered in reaction to questions about the importance of the visual, of imaging in using PET. This researcher was setting me straight about my misplaced interests, revealing in the process the link between world and measurement used by functional imagers:

What we’re doing is acquiring data. Every natural object, a tree, a human, a plane is in four dimensions, it has spatial extent, and it has behaviour over time. We’re trying to measure in those four dimensions.... So instead of probing the brain by making one little measurement, say like people used to do with CO2 coming out of veins, that’s just a one-dimensional measurement over time. There was no 3-D component to that, so now we’re able to measure the brain more appropriately as a
3 dimensional object over time. So you could do that for the brain, you could do that for your foot, you could do that for anything. So the fact that we're scanning in 4-D, is that particularly appropriate or inappropriate for the brain? It's just the same as any other physical object.....(Senior Researcher, trained as physician)

The brain is an object in four dimensions: the goal is to assess these dimensions. But, in this realist mode, the fact that the measurements are displayed over space is not relevant for the object, in the sense that it is not epistemically constitutive of it. (Note however, that the previous technique could only 'probe', make 'one little measurement'.) In this description, a distinction between the object 'out there', and a given mode of measurement is maintained, so that the representation of the data is secondary. This is also a way of maintaining a distance between the scientific work and its 'presentation'. A focus on the representation is missing the point:

Now, is that ever the point of any of these studies, is what the pictures look like? Not really. It isn't. It gives you a good impression of the data quality, many people want to show a data slide, so people can get an assessment visually of the signal to noise. It's hard to trust as data a publication in which you haven't seen any of the raw data. 'Cause it just might be noise. So if they show you their raw data in some form, you make an assessment as to whether you should pay attention to this study, or not. But beyond that what they're talking about is what the mental operation was that they used, what the paradigm was, what trick they used to isolate this out, they may show you a picture to prove that a function that you thought was unitary is really two. And it's two because it has different cognitive characteristics, different reaction times, or, and it's two spatially, and I'll show you a picture of it and it's here and here. So the point is for you to look at that and to admire that it's laid out over space? No the point is so you can see that there's not a lot of overlap, that it's two discrete areas and so two processing areas (Senior Researcher, trained as physician).

But without attributing the (entire) significance of the representation to 'what the pictures look like', I will argue that an important role is played by these 'pictures'. It is important in many respects that these measurements are 'laid out in space'. because this forms the basis of many of the particularities of functional mapping over other modes of measurement of the brain. 'Where' and 'what' are the questions answered by functional imaging, and they are questions that are answered through the use of representations. The representational practices of imagers are therefore embedded in the technologies used, in the experimental methods and in the knowledge claims they make, so that the ways of knowing of imagers are not separable from these representations.

I now wish to move my analysis from the more explicit discussions of representations in the first part, to look at the claims that functional imagers make in terms of the knowledge they produce about the brain. I will show how the arguments made about functional imaging's particular contributions to the study of the brain cannot
be distinguished from the representational strategies described above. One senior researcher, trying to deflate my misplaced interest in representation, explained the constitution of representations in functional imaging as simply following the logic of putting the information about activity where the area lies in space (Senior Researcher, trained as physician). Nothing magic about it, said another researcher. But each of the elements of this strategy has a complex history. Each of these elements also participates in the claims of functional imaging in relation to other disciplines. The detection of activity, its attribution to an area of the brain, and the construction of a ‘space’ for relating these two elements are all based on representational strategies of functional imagers which differ from those used by other groups.

The research pursued with functional imaging technologies and methods is construed by its practitioners as the cross-roads between cognitive psychology and neuroscience:

"...it has come to the point, as it often happens in science, that a discipline arises between two existing disciplines. I don’t think that will go away. The discipline is not PET and fMRI. It’s all the methods for imaging: evoked potential, MEG, united around the fact that we can do things with the human brain that we never could do. ... It’s not cognitive psychology, it’s not neuroscience, it’s somewhere in the middle.... (Senior researcher, trained as psychologist)."

The rest of this chapter will analyse how representations play a role in the way researchers construct a middle-ground between researchers of the mind and researchers of the brain.

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121 In order to check whether my own interest in the visual had not provoked many of these comments, I looked to other studies of PET to see whether these kinds of explanations were also offered—and that seems to be the case. Fragments from Dumit are quoted in the chapter, and the following quotation from an interview by sociologist Anguelov, exploring rather different questions (though related, because about ‘world formation’) contains the elements also evoked in the interviews I did. He explains:

Although PET is largely identified as ‘imaging’ technique, the fact of the matter is that the first step in PET is to collect quantitative data: every single positron emission is measured in a tri-dimensional space (and recently time has been added as a fourth dimension by the front PET researchers). It is at the next step that the bulk of measurements is digitally transformed into an image by the computer. But nothing can constrain researchers from using the data as measurements, i.e. in a statistical way. This trend is now gaining ground, and PET researchers from the MNI are at its leading edge. As a matter of fact, one of the leading PET runners was critical to the whole PET field that it still sticks to the image instead of providing more rigorous results from quantitative data only (Anguelov, 1994).
For the first time in the history of neuroscience, it is now possible to 'observe' cognitive activity in the intact human brain.\footnote{From Cabeza and Nyberg (1997).}

Functional imagers stress the power of brain imaging technologies to encompass the entire brain of normal subjects. The space enclosed by the skull\footnote{The goal of penetrating the head with x-rays and the resistance of the skull was noted early on in the history of x-rays, as early as the turn of the century (Kevles, 1997). Attempts were also made with ultrasound (Yoxen, 1987).} has been penetrated:

"These technologies have breached the biological limitations imposed by the inaccessibility of the functioning brain to direct observation and investigations, since they allow direct assessment of brain function in the normal living human being (Volkow and Tancredi, 1992)."

The elements of directness, in vivo study and normality which the technologies allow are considered truly unique to functional imaging. Furthermore, brain function has become more directly accessible. This is a common formulation of the powers of imaging. Being able to view the normal human brain, for example, has meant studying different kinds of subject:

"While CT was a means of viewing the internal anatomy of the human body, PET extended that view to organ function. Brain-behaviour relationships in human, long the province (sic) of neuropsychologists and cognitive psychologists studying patients with brain lesions, could now be pursued with rather remarkable accuracy in normal subjects as well (Raichle, 1996b)." 

Rather than relying on accidents of nature (strokes, tumours) that would affect function and thereby give some (indirect) information about the localisation of functions, researchers could study activations in normally functioning brains—function, rather than disrupted function. It also meant a different approach than intra-operative stimulations, which were done on patients with brain pathologies justifying such interventions. Furthermore, because the imaging technologies can retrieve the signal of the brain 'non-invasively', the space is undisturbed, considered normal. Again, this contrasts with the intra-operative stimulations, which are done on patients whose brains are affected by tumours or other abnormalities. This is also a shift from another 'direct' mode of study, which consisted in studying patients with lesion in life and correlating their dysfunctions with post-mortem studies of brain anatomy.\footnote{A similar technique-based coupling of body and technology to produce a graphical mark was applied by Marey in physiological studies, also implying an important shift in methodology: the object studied and the production of the trace become interdependent (Cartwright, 1995).}

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Being able to see inside the brain space in vivo relies on features ‘built into’ the technologies used in brain mapping. Both ‘origin stories’ and technical descriptions of PET insist on the importance of the creation of the means for reconstructing images from the measurements made by the detectors. For example:

x-ray ct “immediately stimulated scientists and engineers to consider alternative ways of creating images of the body’s interior using similar mathematical and computer strategies for image reconstruction. This quickly led to the introduction of positron emission tomography (PET) which was in effect, a means of doing tissue autoradiography in vivo in humans (Raichle, 1996a).”

The manipulation of data in different space, retrieving the space of the brain inside the scanner is considered foundational to ‘modern’ or ‘mature’ PET technology. Specifically, PET III is often referred to as the first of ‘modern’ PET scanners, because it used coincidence detection and reconstruction algorithms based on the algorithms developed for CT by Hounsfield, and Cormack in 1972. In order to be able to measure “in 4-D” therefore, the relation between the space of the brain inside the scanner and the space of the digital image had to be constructed. Representations in PET imaging are the product of the recovery of the origin in space of the signal, and this is built into the scanning technology. Tomography, the technological possibility of making these kinds of images, is also the key to placing brain activity in space.

A further line of argument also corroborates the significance for functional imaging’s contributions of having a spatial dimension: new technologies, such as MEG, and older ones ERP/EEG have been enrolled as part of the armamentarium of functional imaging in the early nineties, on the basis of the spatial information they could convey. This shift is visible in descriptions of the technologies, in editorials, or articles which review functional imaging. This is due, in part to developments in modelling that allowed better attribution of the source of the signal (Wood, 1994) and in an increased the number of sensors (from 12-20 sensors to arrays of 120-150). This resulted in a better link of the activations to specific sites; the source of the signal is less uncertain than before, when different types of activations could have been responsible for the same detected pattern (Mountcastle, 1998). For example, the EEG/MEG were added to the ‘subtitled list’ of technologies of the Journal of Neuroimaging in 1994, stressing that they were now able to contribute to the study of human cognition and perception as well as clinical use because they could be made spatially relevant. The notion of space is determinant: MEG “is treated as a brain imaging technique rather than as a type of ERP recording because

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126 Developments in computer power are also sometimes mentioned, although as is often the case in these types of histories, the reliance on computational power, a technical feat, is backgrounded in favour of the intellectual advances allowing image reconstruction.

127 The current form of PET scans is also traced back to the constitution of a ‘functional image’ (Dumit, 1995).

128 Andreassen (1988) lists SPECT, CT, MRI, and PET; by the mid-nineties, the oral sessions of the Conference on Functional Mapping of the Human Brain consciously aim to include studies done with techniques such as MEG and to include EEG and MEG in the ‘short course’ offered to attendees.
most recent MEG methods provide a ‘map’ of activity over the whole cortex. (Hugdahl, 1995).“

As these technologies provide spatial data, they come to be considered as part of the brain mapping ‘box of tools’. This association tells of the centrality of spatial information of functional imaging technology. Tools are appropriate if they can provide data about the brain in such a way that they can be represented in space—precisely as ‘measurements laid out over space’.

If PET provided tomographic data, having data represented in a physiologic space was not meaningful. The need to create a special space in which to understand PET was an important item on the agenda of the growing PET community in the early eighties. Without repeating all the arguments made in chapter 2, it is useful to note that the spatiality of PET measurements has long been a core concern. PET was said to present “a challenge to an old discipline”. It provided physiological measurements in the space of the brain that had to be both distinguished and reconciled to the anatomical space of the brain. The physiological space was eventually constructed so that it could be layered onto an anatomical space: representations in 4-d are the product of PET methodology and technology, not an afterthought.

These efforts in functional imaging have resulted in technologies that produce traces in explicit spaces, and modes of analysis that rely on well-defined spatial components and anatomical referents. These are not post-hoc contextualisations of functional imaging data, but are integral to obtaining it. These elements of functional imaging are also relevant to understanding the other claims made by functional imagers. The pictorial and spatial aspects of anatomical imaging technologies are also found in the construction of PET scanners and their interpretation.

**Trope 4 Concreteness of Scans**

“For functional specialisation, every guess was that there was some specialisation. It came as no surprise that you would get these little patches when you stimulated people with motion or colour, there was no great paradigm shift, but by virtue that it was clearly evident, that you could see the functional specialisation in action, it suddenly acquired a concrete status that it didn’t have before (Senior Researcher, trained as physician).”

New evidence using functional imaging techniques provides a ‘concrete status’ to theories of brain functions. Since these studies are done in humans, the full range of the mind’s functions can be studied, and also made concrete. Specifically, many of the ‘higher cognitive functions’ are in the frontal lobes, so that animal studies are of ‘limited use’ since “the biggest discrepancies between man (sic) and animal are found in the frontal lobes (Frith et al, 1991).” Finding biological traces of mental processes and illnesses has also been proposed in cognitive psychology and psychiatry.
The normal human brain can therefore be used as a basis for those studying the mind:

"The goal of cognitive neuroscience is to identify the neural substrates of cognitive processes. Our chances of achieving this goal have radically increased during the last decade by the introduction of functional neuroimaging techniques (Cabeza and Nyberg, 1997)."

The need to link cognitive activity and the brain is a revision of the cognitive sciences agenda as discussed in chapter 3: "Those cognitive scientists interested in a deeper understanding of how the human mind works now believe that it is maximally fruitful to propose models of cognitive processes that can be assessed in neurobiological terms (Gazzaniga, 1989)." Brain imaging provides such a tool for deepening one’s understanding by exploring the space of the brain. The possibility of seeing the brain provides a more scientific basis to cognitive neuroscientists:

"It is important to emphasise that cognitive neuroscientists are eclectic in their mode of experimental design and methods of execution. However, the coincidence of this new field with the appearance of new methods for imaging the workings of the human brain has established cognitive neuroscience as an important enterprise in the human brain science, one in which the mapping studies using imaging methods now coalesce (Mountcastle, 1998).

The imaging technologies provide more scientific methods in the eyes of this prominent physiologist, by apprehending the concrete brain rather than the elusive mind. Functional imagers often point out that psychologists do not deal with the brain, but with a construct they call the mind. What the functional imaging methods have to offer is a grounding in the brain of these constructs:

"It all depends if they care about where things are located in the brain. If they’re cognitive psychologists, then they don’t understand that all objects are in 4 dimensions, not just one. Cognitive psychologists tend to think of the mind as being only in time. But the mind has a physical counterpart, the brain. And if you want to adequately study the mind, you need to study the brain as well. And that moves you into four dimensions, and that means you actually represent where the properties are in those three dimensions, and that you need to study them, in space, over time. and that is a shortcoming of theirs (Senior Researcher, trained as physician)."

The brain as a space in which/through which the mind is to be studied is overlooked by psychologists, focused as they are on ‘process’, in terms of time, and not on the ‘implementation of these processes’.
The way in which the mind is made concrete through being studied with functional imaging again focuses on the use of elements of the anatomical tradition. The subtraction method based on Donders’ work is adapted here so as to be the measurement of activity laid out in space. The contrast between the tasks represents a particular ‘operation’. The operation is then considered to be implemented in the area (or areas) that differ.\textsuperscript{128}

It becomes clear why the adaptation of the Donders method from time to space is determinant in translating much of the phenomena of cognitive psychology into phenomena that can be studied with functional imaging. This experimental approach has been rather inelegantly formulated as the ‘where’ question. Thus, ‘where’ has been described as the question about the human brain best answered by brain mapping’s converging disciplines (Wood, 1994). But ‘where’ has not always been the key question for cognitive psychology, (Posner and Raichle, 1998). “The particular contribution that functional imaging provides is to penetrate the brain space and allow the study of the mind in that space rather than treating it as a series of events in time (represented as a series of boxes).

“...the critical thing about non-invasive techniques are one, you can investigate and measure human brain function in life. There is no other way of doing that, other than by pencil and paper, talking tests. But that sort of testing doesn’t actually tell you anything about how brain function is implemented in the material substance of the brain. It tells you nothing about which areas of the brain are involved, how their activity’s integrated, what the substrate for these brain functions is (Senior Researcher, trained as physician).”

Representations make this argument very powerfully, since they render mental phenomena measurable, and place them in space. Contrasting approaches in neuropsychology and imaging, this respondent highlights the concreteness of using representations and links it to its visualisation:

“It’s really boring to get up there and say, well, I have this patient and he has a lesion in the brain here and he can’t do this task, or just get into this little nitty gritty detail about a particular cognitive function of interest—cognitive function of interest are thought about in an abstract level and are not easily visualised.....Most phenomena in psychology you cannot see (Junior Researcher, trained as psychologist ).

\textsuperscript{128} For those conversant with this particular methodology and the critiques often levied against it, the assumption of ‘pure insertion’ (that tasks can be considered as independent building blocks, and hierarchically ordered in an increasingly complex task in an experiment) is also reproached to functional imaging. Because of the shift to a ‘visuo-spatial’ mode of measurement, however, the case is made that if the brain begins to use a different strategy altogether rather than ‘linearly’ recruiting more areas, this will be ‘visible’ to the experimenter; the assumption can be checked.
Another psychologist recounted the experience of going to psychology conferences and "having people come up to you and say, 'wow, you've got a brain on your poster'" (Junior Researcher, trained as psychologist). Measurement laid out in space does count.

Accusations of a lack of sophistication in manipulating the 'function' being studied have been made by some cognitive psychologists (as noted in the discussion of 'pretty pictures' above). But the measurements of cognitive scientists are less 'direct', to the imagers:

"by observing the input and output responses, ... they are not able to demonstrate the mechanisms by which the organ works. This is formalistic, whatever boxes they put in, these boxes are not ontologically committed, so that's a major drawback. (Senior Researcher, trained as neuroscientist)"

Because based on external measurements (reaction-time or accuracy of responses), cognitive psychologists can only provide an indirect measure—indirect, in the sense that it will not measure activity in the space of the brain. Pinker makes this contrast between psychological experiments and imaging work:

"More generally, I wonder whether PET research so far has taken the methods of experimental psychology too seriously. In standard psychology we need to have the subject do some task with an externalisable yes-or-no answer so that we have some reaction times and error rates to analyse—those are our only data. But with neuroimaging you're looking at the brain directly so you literally don't need the button-press or the overt blurring (Pinker, 1994)."

The concreteness of measuring mind phenomena in the brain also led this researcher to use PET. He had been working in a group where he was at the 'top-end', the mind end, while his colleagues were more biologically-oriented researchers. Imaging provided the possibility of 'testing', of finding a physical basis to his 'boxes':

"... And I produced various theories about how hallucinations or whatever might relate to brain functions or whatever. But of course it was impossible to test them at that time. And there were a series of lucky coincidences, in that in 1988, the first thing that came out in Nature and Science almost at the same time, by Posner and Raichle and others, where they used PET, specifically to look at cognitive components of language. And up to that time I hadn't read anything about it. But this was directly taking a cognitive psychological model with all these boxes, as I'm sure you know, with all the arrows, saying this box is in this bit of the brain, and we're able to determine this by doing PET scans. So I was obviously very excited about this, because my work was full of these boxes and I had thought in this case I can find out whether the boxes exist and where they are. (Senior Researcher, trained as psychologist)"
Functional brain imaging is therefore the constitution of spaces for measurements and measurement of activations in relation to those spaces. While the point may not be about how the pictures look, it is very much about seeing the activity being laid out in four dimensions. Showing that mental processes are somewhere in the brain relies on the technologies and methodologies of space reconstruction of PET and the subtraction method. By making and showing their measurements in the brain based on spatial differentials, the anatomical level must be rendered, reintroducing the pictorial in the representations of functional imagers.

**Troppe 5 Seeing the Entire brain**

"...you find a brain correlate, namely change in blood flow. Of course, compared with EEG, it's a better correlate. It's better defined spatially, and it covers the entire brain (Senior Researcher, trained as neuroscientist)."

Another distinctive claim of functional imaging is the possibility of imaging the entire brain. This has implications for demarcating imaging work from both neuroscientific approaches and neuropsychological studies, which have been concerned with localisation or mapping work (in the general sense of attributing functions to locations). Being able to measure the entire brain is used to contrast functional imaging with other modes of measuring the brain. Other methods make 'one small measurement', by 'probing' the brain as described above, whereas functional imaging can encompass the entire brain.

The apprehension of the brain in its entirety provides a different territory for investigation than the space of the brain that is available to other methods, such as intra-operative stimulation, where only a very small part of the brain is visible and manipulable. Since localisation research is the coupling of function and location, a different version of a territory leads to different definitions of functions. The possibility of measuring all processes in the entire brain subordinates the claims of functional imaging that it can investigate the brain at a 'systems level'. This argument is often used to show the break between the localisationists of the 19th century and functional imaging. Since they do not equate one region with one function, systems-levels investigations mark this type of mapping as a new endeavour. Thus, in contrast to traditional methods of neuropsychology or intra-operative stimulation, functional imaging does not show only the essential areas for a function, but an entire system that subtends a function. Measuring activity in the brain at a 'systems level' has been an important result of collaborations of psychologists and neuroscientists:
"First, as you know, the results are bound by the methods. So if you work with single unit recordings, you tend to be short-sighted, you will understand some details of local computations, but you have no idea whatsoever, how the organ is functioning at the systems level. Nobody had any ideas about the function at the systems level....and one of the major landmarks is this immense, we can call it parallel processing, but we call it multiple neuronal populations or multiple synaptic populations collaborate to produce functions of the brain....[neuropsychologists] tend to interpret their results in the traditional localisationistic way. They had no idea how dispersed, I wouldn't say diffuse, but dispersed it really is...the brain really does work this way with these huge populations. So I think that's very fortunate. That is why the methods are so efficient. (Senior Researcher, trained as neuroscientist)."

According to this pioneer of functional imaging, without being able to measure these entire systems spread all over the brain, the way the brain works could not be understood. Being able to consider functions as systems, (and not as 'unitary', with particular places in the brain, which once removed will affect only that one function leaving the rest of the brain undisturbed), is "a major methodological leap, a change of mindset." Functional imaging also claims that it will inform physiologists about where to place their recording devices.¹²⁹ Such claims of measuring the simultaneity of activations of parts of the brain, of measuring at the systems levels relies on detecting groups of areas connected in space and the layering of functional and anatomical information.¹³⁰

Thus, in spite of the distantiation from imaging and the visual discussed in the first part, the arguments and claims of functional imagers rely to a great extent on aspects of representations from these traditions. In this section, I have examined a number of 'redefinitions' in relation to functional imaging. What constituted a 'modern' PET scanner, what makes a technology a functional imaging technology, what constituted a proper basis for analysing PET data. The answers to these questions have to do with the possibility of providing spatial measurements. Linked to these modes of measurements are the particular knowledge claims that have arisen from functional imaging: seeing the brain at a systems level, making mind phenomena visible in the brain. These claims which set functional imaging apart from other approaches and other groups of investigators are linked to the representations of functional data in a dimensional space:

¹²⁹ In relation to neurophysiology, there are problems about knowing where to place the electrode to sample brain activity. Note how the common element of space may enable communication across these techniques.
¹³⁰ Not surprisingly, if psychologists and cognitive scientists question the notion of 'function' that is used in these studies, neuroscientists' criticisms come from the brain end. They challenge the meaning of the signals detected by PET. Here too, hierarchies of evidence are at play. Recent pronouncements on the foundational principles of neuroscience state that the ultimate cause of mental activity is the neuron—so people doing EEG measurements see imaging as very indirect, because blood flow is coupled, but sometimes loosely so, to the activity of neurons. Researchers dealing with measurements of neuronal activity are sometimes critical of imaging. One researcher who had moved from research using EEG to imaging described going from "evidence to suggestion", from physiology to metabolism. The link between neuronal activity and blood flow has been a controversial topic in the imaging community.
the pictorial conventions of anatomical knowledge are mobilised to relate functional data to the substance of the brain.

Mixed traditions, Hybrid Objects

After about ten years of functional imaging research, there have recently been calls to review the research agenda. Interestingly, many of the criticisms of the current state of research and proposals for future developments also point to the place given to representations in functional imaging. The results provided by functional imaging have been labelled as limited, because ‘geographic’ (Mountcastle, 1998). While the ‘neopnenology’ of the past years has been necessary, and continues to provide unique insight (into the entire, normal living human brain...), researchers need to consider it as an empirical basis and not as an end in itself (Frackowiak, 1998b). Knowing the answer to ‘where’ should be used to answer questions about ‘how’ the brain works. These representations should be used as the empirical basis of further analysis; as observations on the basis of which researchers can theorise; as the materials from which ‘principles’ of brain organisation will be discovered. Maps will lead to principles and to models of brain function.131 As one researcher predicted: “So once the field grows up becomes less interested in mapping, it will be numbers (Senior Researcher, trained as psychologist)”. Such statements makes sense in terms of the scientific hierarchy of evidence with which this chapter began, and which was shown to be embraced by the researchers using imaging. Accordingly, functional imaging aspires to scientific status; an empirical basis is built; as a field matures, the representations used will be purified and tend towards the quantitative. This may be yet another rejection of the visual, to discover by non-visual means what is “hidden beyond the phenomenal tide” (Stafford, 1991). If the current research agenda is transformed to address other questions about the brain, the style of empirics will also change, the importance of representations will be altered.

Others predict that future development is possible for brain mappers, although

“the acceptance of brain mapping data, either from an individual modality or provided in composite, will be enhanced by display approaches that provide data presentations and images that are immediately recognisable to individuals with a knowledge of cerebral anatomy (Mazziotta and Toga, 1994).”

Data will have to be translated into a form that allows a visual understanding, the immediate, clinical, image-based use. If the results of research are to be ‘applied’, representations will have to be adapted to a different understanding—the measurements of scientists will have to be brought more closely in line with the anatomical tradition of the clinic.

I have analysed here the complex understanding of representations by functional imagers in terms of the demarcation of a new approach to the study of the brain. As seen

131 See for example “Principles or Maps” (Friston, 1998).
in the first part of this chapter, the work done using representations is defined as scientific and quantitative, the making of measurements. These measurements can be ‘visualised’, but they are not constituted nor are they understood as images, as pictorial representations. Researchers distinguish their work from that of the visual detection of the clinic by insisting on defining their work as quantitative measurements. Representations may play a useful, communicative role, but they are not determinant in the work pursued. In the second part, I examined how other kinds of distinctions between how imagers see their work and that of others are made. By constructing their practice as dealing with the activity of the mind, and showing this activity in space (directly, at a systems level and in normal brains), the functional imagers define an approach that is very much bound up with the use of representations. Researchers prefer to define their work as measurements, which are the results of manipulation and experimentation. But the very constitution of these experiments is based on the possibility of representing data in space, and layering the activity of the mind onto the brain.

Making ‘images of mind’ in a bounded brain provides a basis for biological explanations of behaviour. Functional imaging research has been directed at finding the physical substrates of mind, and the underlying causes of deviant behaviour and disease. In some ways, this project is comparable to the phrenological and localisationist projects of the nineteenth century, where faculties were linked to bumps and pathological functions to brain regions. But brain mapping is constructed as measuring activity in the complex space of the living, acting brain, rejecting both the shallow study of surface of phrenology, and the anatomo-clinical stance of the localisationists’ post-mortem correlation.

At the heart of the paradoxical understanding of representations in this field is the dual appeal to the graphical and pictorial. Functional imaging makes use of the pictorial tradition of anatomical representations, to provide spatial referents to the data it produces (activity in the brain) and convey the notion of control of the space of measurement (seeing the entire brain). Yet it also distantiates itself from the traditional visual understanding that accompanies these anatomical representations, and invokes a graphical tradition where the correspondence of image to world is one of quantity and measurement, not one of depiction. The functional imagers’ hybrid object of the mind in the brain is constituted by the juxtaposition of hybrid representational traditions.

By observing the hopes and anxieties around representations, this analysis reveals important dynamics in the constitution of a scientific, research-oriented project. What constitutes relevant empirical strategies are deeply rooted in material, disciplinary and institutional contexts from which this new project arises. Numerous case-studies have shown that all sciences deal with signs, and that differences in 'epistemic cultures' (Knorr-Cetina, 1996) or traditions (Galison, 1997) can be observed. This chapter shows that cultures can also clash, and that seemingly contradictory statements are in fact sensible in highly specific, hybrid contexts—the repercussions of empirical dissonance (image/number). Galison has suggested that new forms of imaging, using computerised
counters which turn numbers into images, has marked the integration of traditions of evidence in physics:

"the tension between analog technical knowledge and digital technical knowledge is a deep one and that this division has cut across disciplinary boundaries. The weaving together of the two traditions in the last few decades represents a previously hidden unifying trend in an age of scientific specialisation, Homologous and homomorphic representations have coalesced." (Galison, 1997).

The case of functional brain imaging shows rather that, while kinds of knowledge have been integrated to some degree, and reshaped to some extent, differences do endure. This may be because Galison's case examines these traditions within a lab situation. Functional imaging has had a much less structured environment, so that different traditions of evidence live on in the clinic and in the various places of work involved, challenging and destabilising these attempts at syncretism. While the use of images seems to be increasing, the intersection of the visual and digital culture implies a redefinition of the visual, especially when understood as 'pictorial.' The new quantitative anatomy constitutes an important example of such redefinitions.

Furthermore, this attention to the empirics of brain mappers not only makes sense of the rejection of the clinical visual diagnosis discussed in the first part, but it also explains the particular version of anatomy developed by brain mappers (the many permutations of the x, y, z Talairach brain space). Functional imagers do not value the skills of recognition of the neuro-anatomists or pictorial evidence, and instead invest the space of the brain with a graphical efficacy that allows quantitation and calculation.

This analysis also makes sense of the ambiguous relationship of researchers to the representations they use, and proposes that this relationship is the result of the aspirations of brain imagers in terms of scientific credibility on the one hand and on the other, of the ways in which they carve out a terrain of particular expertise in relation to other disciplines. These two elements can be shown to sustain both an iconoclastic stance towards these representations, while also providing motivations for the sustained use of representations.

The paradox of images in functional imaging results in the attempt to segregate various aspects of representations. Hence researchers separate the visual appearance from the content, seeing from reasoning, imaging from experimenting, yet rely on the synthetic power of representations to make their object, and to inscribe new phenomena in the space of the brain. While efficiently evoking control and knowledge of space and simultaneity of measurement, representations must be used with care and cannot simply be presented as visual proofs, without endangering claims to scientific status. Even in non-scientific contexts, the visual argument must be used circumspectly. The technological feasibility of visualisation is at least partly shaped by existing scientific criteria of validity and acceptability of evidence. The next chapter will consider digital
tools and imaging databases, and will show how new objects can and do arise in a context where the quantitative image is the starting point.