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Chapter 1 New Views of the Mind-in-the-Brain

Mapping the Mind onto the Brain

The last decade has been marked by great changes in the fields of psychology and neuroscience. These changes have been highlighted by the declaration of the 1990s as the Decade of the Brain in a number of countries, and the instigation of the Human Brain Project in the United States. During this period, new views of human mental function have been formed through the development of new technologies and new mapping strategies for relating the mind and the brain. The objects of study of various disciplines and specialties have thus changed in ways that have affected the larger cultural context. Institutional arrangements that rely on mind/brain distinctions have also been implicated in these shifts in scientific research. For example, through the use of brain imaging technologies which show aspects of decision-making processes in the brain, rationality, responsibility and intent as key concepts in legal settings are being redefined (Kevles, 1997)(Kulynych, 1996). Understandings of subjectivity are also changing as we come to think of mental illness, or of learning disorders, as having primarily a physical basis (Dumit, 1995).

This book aims to trace these changes by focusing on a core project that arose between the mid-seventies and late eighties, and was consolidated during the nineties, namely ‘brain mapping’. Brain mapping is an evolving notion, but in its simplest terms, it can be described as the practice of correlating activity in the brain with specific anatomical areas. Usually, the activity is a physiological trace, to which psychological meaning can be attributed. The development of brain mapping has marked an important transformation of experiments in some areas of psychology and neuroscience. Through scanning experiments, phenomena which had been studied using behavioural measures came to be studied using brain-based, and more specifically, combined physiological and anatomical measures. In contrast to a focus on processes of mind in time, brain mapping redirected attention to patterns of activity located in the space of the brain.

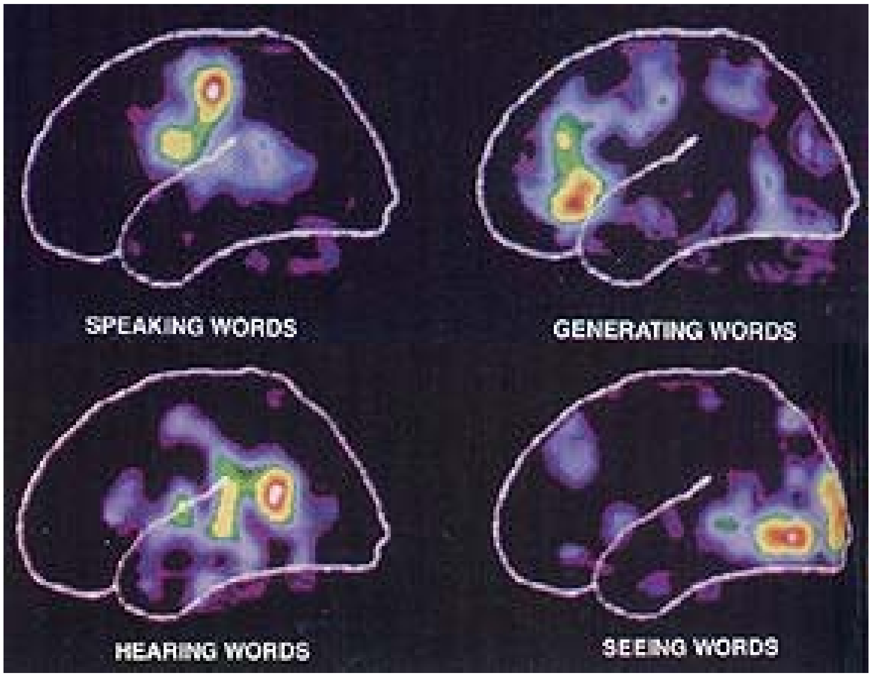

Figure 1 Hearing Words, Seeing Words.

This is the psychologist's rendering of brain mapping. The space of the brain is clearly present, the outline marks the space in which function occurs, but the most prominent aspect ise the floating rainbows, which, though anchored in the brain, most dramatically depict function against function. In the same way that the nineteenth century physiologist Marey's visual measurements removed depth, and all other elements not involved in motion and temporality, so this image, which became the emblem of mapping, shows the cognitive brain. The rainbow acquires an iconic role in showing activity, while structure is depicted as white outline (as above) or in the grey scale of x-ray tradition, with some variations to other (single-tone) scales, such as 'hot metal'.

(awaiting permission)

These 'localisations' have grown in sophistication in the course of the 1990s and into the present decade, and an increasingly complex set of features of the mind can be mapped onto the brain. Life experiences, the impact of environment, and learning, have all been studied in mapping experiments. Maps have been produced contrasting how language is localised in early and late bilinguals. The superior spatial memory of London taxi drivers, who must learn the city centre's many streets by heart ('do the knowledge') in order to be accredited, has also been mapped as biologically different. Even a concept steeped in cultural determinants like racism can be translated as a reaction in the brain in this stream of research. These maps link social, psychological and environmental factors to the biological structure of the brain. Given the scope of these maps, it is therefore not surprising that besides changing the ways many psychologists and neuroscientists work, these maps have also been at the heart of new kinds of arguments and debates. Mapping can thus be said to reconfigure the nature/nurture debate, for example. It is not the case that only nature is considered to matter. Rather, nurture also counts, but only once translated in to a measurable activation in the brain. Biologisation of mind in brain mapping takes the social or the environmental rather seriously. It renders these as features of a map. In the popular magazine Newsweek, the fate of deprived Romanian orphans was prominently compared to that of normal children through a pair of PET scans, the images standing in for the impact of emotional neglect as measured in the brains of the orphans (Begley, 1997). In this case, lack of nurture was shown as a biological feature. More recently, brain maps have further shaped the way the nature/nurture question is being posed. A study of twins' brains (Thompson et al., 2001) has linked brain scanning with genetic variation. This study also correlated cortical structure and IQ test scores in relation to genetic influence. What is happening in this instance is not the refusal to accord importance to non-biological aspects of psychological function, but rather, a complex translation of phenomena into measurements of the brain. This occurs in two steps. First, the volumes of parts of the brain are measured and correlated to degrees of genetic similarity (through the well-known strategy of comparing monozygotic and fraternal twins). The variations in volumes can then be attributed to genetic or environmental factors. This particular study further suggested a possible mechanism to explain hereditary factors in IQ scores—volumes of grey matter were strongly genetically determined, and could in turn be related to the scores obtained by subjects. Differences in measurements of intelligence, differences in degrees of kinship, and differences in environment and experience could all be compared in this study, because they were translated into features of voxels, the digital units that make up brain scans and serve to calculate and correlate volumes and levels of metabolic activity. These maps, produced using digitised data and large databases, therefore powerfully redefine concepts like behaviour, nurture, culture and environment. Furthermore, maps play an important relational role, linking context, mind and brain.

The Contested Terrain of Physical Minds and Virtual Brains

This stream of research is not unconstested, however, and its methods have developed over time, in response to new criticisms and hopes from increasingly diverse settings. Brain mapping has been amply discussed, praised and rejected by researchers in terms of its results and contributions to understanding the mind/brain dichotomy. In reaction to claims of being able to 'see the mind', brain imaging has sometimes been (pejoratively) presented as positivistic, an endeavour limited by researchers' failure to address the meaningful content of what they are imaging:

> "One must think about what it means to the brain to be part of a human subject paid to lie in some machine while performing more or less stupid tasks (and most of the paradigms studied in the actual brain function/cognition projects with imaging are so simple that the brain will never be confronted with them in real life) (Schmitt, 1995)."

In this view, mind is the meaning of brain processes, and this remains beyond the reach of these imaging experiments. For others, the successes of imaging are at best marginal, exploring only what is at the edges of 'mind'. A reviewer states that while the authors of the popular book on functional brain imaging, entitled <u>Images of Mind,</u>

> "seem to have gone out of their way to make the results of PET scans seem humanly and psychologically meaningful, … this effort can most generously be called a limited success. PET scans have indeed provided us with 'images of

> mind', but only of very few simple aspects that, by and large, really do not tell us very much about how the mind as a whole behaves (Goertzel, 1995)."

This reviewer further hesitates as to what these results address, and goes on to say that "at present, however, the scans…feel more like 'images of brain' than 'images of mind' (though the latter is also a perfectly accurate description) (Goertzel, 1995)." While the imaging technologies have not yet delivered, and though they leave the reviewer unsure as to the status of the object they show, (mind or brain or are these both the same), the promise of these experiments does not leave him indifferent, as becomes apparent from the rest of his review. Indeed few have remained unmoved by brain mapping, reacting to its claims, costs or vivid images. In more enthusiastic evaluations, research that uses brain imaging technologies has been widely presented as an exploration of mind in scientific (because material) terms. 'Consciousness research,' often labelled the hardest question in cognitive science research, is said to be making a comeback; the contribution of imaging research makes it into an empirical discipline. Many discussions setting out research agendas have defined mind and brain, subsuming the former to the latter:

> "Another term for this complex of cognitive processes that are in many ways uniquely human is 'mind', which is not to be taken as some mystical entity but rather as a description of the functional properties of our brains that render us human. Thus the study of human cognition and perception is in a very real sense the study of the functional properties of the human brain… One aspect of the study of human cognition and perception is the use of various non-invasive techniques, such as PET, MRI, ERP, and MEG to discover the neural correlates of human cognitive and perceptual activity (National Science Foundation, 1991)."

The scare quotes around the word mind, and the prescriptive formulation warning against mystical views, are indicative of tensions in brain mapping research (which will return in the course of this book), between a materialistic philosophy of experimentation and dualistic notions limiting what can be known about the mind. Indeed the healing of a Cartesian breach has been a recurring trope in discussions of functional imaging technologies: these scientific experiments move from brain to mind as though the philosopher's division had never existed. Taking an even stronger view, some have announced the death of the mind:

> "The time has come where brain function, from emotion to mentation, imagery, intention and so on is definable, in the relatively crude terms that we can define it now, in the substance, the material substance of the brain. So things like soul and mind and so on become useless, no longer of any use in scientific discourse (Senior Researcher, trained as a physician)."

During the same period, there have been appeals to scientists to accept that the brain has "dimensions", along which it can be studied, though some are "repelled by a reductionistic approach which has proved so successful in understanding other organs of our bodies (Koshland, 1992)."

The Mind-in-the-Brain

The working brain, visible in a PET scan, is therefore presented by researchers, in turn, as touching the hard core, or as (literally) mindless reductionism--with less extreme versions of each view in between. The notions of mind and brain are important concepts for researchers in psychology and neuroscience, which determine what can legitimately be claimed, questioned and investigated in the course of research, as well as delineating who is qualified to pursue these investigations. The few arguments presented above provide a glimpse of a partial reconfiguration of the mind and brain dichotomy through brain mapping research. The consolidation of the biological basis of mind in relation to brain mapping is especially of interest here.

Bounding the brain and studying it according to its ‘dimensions’ requires a number of shifts and innovations in social and technological arrangements. These are all the more complex, as the brain becomes the place from which to study the mind. Brain mapping research is often discussed in terms of a ‘window onto the brain’, through which the workings of the brain termed the mind can be observed. The assumed transparency of the technology participates in important ways in the discourse that collapses mind into brain. Accessing the mind is presented as a matter of developing a technology to look at the brain, to penetrate the space inside the skull. But technologies do not render nature in any self-evident way. And when they seem to do so, it is the result of complex processes. These processes are all the more multi-dimensional when, as mentioned, a number of technologies and disciplines are involved, as is the case with brain mapping.

Therefore, rather than showing the development of brain mapping as the desirable or harmful evacuation of one term of a mind/brain dichotomy through technologically-mediated discoveries, I will show how these objects are recast. By asking ‘what is the brain’ and ‘what is the mind’ being investigated through these technologies, it becomes clear how traditional boundaries come to be blurred, and how these objects come to be superimposed onto a map. I will argue that in the course of developing a mapping practice, a different object, the mind-in-the-brain, is constituted. Recasting the question in these terms not only de-essentializes scientific categories, but it also points to the importance of processes of technological development and institutional embedding for the constitution of these objects. The neologism of the mind-in-the-brain underlines the translations and transformations performed (especially by cognitive scientists) in order to make their object of study. It highlights how these researchers present the specificity of their claims, in addressing the neural correlates of cognition. The term furthermore characterises the stance of researchers who reject the word mind, while still invoking as their object of study the wonderful functions that make us human. Hence, the brain-in-the-mind is analytically useful to understand how 'mind' is subsumed to 'brain', and how this constitutes a special claim in relation to a posited (pre-existing) tradition where these terms are separate.

Brain mapping as a hybrid research

Brain mapping is a very heterogeneous research endeavour. One reviewer noted that the textbook ‘Brain Mapping: the Methods’ failed to provide a definition of what this is, leaving the reader to figure out, by default, that brain mapping refers to the diverse contents of the book. Even the label for this work has been the object of discussion:

functional imaging, brain mapping and imaging neuroscience have variously been used to describe the stream of work that will be traced in this book. Significantly, arguments for particular labels are often formulated in terms of the need to associate or distance research from the technologies used. Functional imaging has indeed grown around a number of technologies constructed in the seventies, and relies to a large extent on the development of digital as well as scanning technologies.

Among these many tools, positron emission tomography (PET) is often called the workhorse of functional imaging. PET's development is typically presented by participants as bringing together research streams from physics, chemistry and mathematics. The following events are often mentioned: the first PET conference was held in 1978 at the Montreal Neurological Institute (Canada); a clinically-applicable 'early' PET was built around 1975 inspired by the work on CT scanner; 'mature' PET and the first commercially produced PET with cyclotrons were available by the mid-eighties. While currently closely associated with neuroscience and cognitive psychology, PET was developed in nuclear medicine and neurology contexts (Kennedy, 1991; Kevles, 1997). It was first applied in the early eighties to measure cerebral blood flow and metabolic abnormalities in the brain, such as high-energy consuming tumours. It was also used for pre-surgical evaluation of epileptic patients, a clinical practice in which a different type of mapping was often performed during surgery. Later used in combination with other imaging technologies, PET studies in brain mapping research allow the localisation of cognitive functions to particular areas or groups of areas in the brain. The experimental methods for localising cognitive activity with PET were developed in a series of studies in the course of the eighties (See Figure 1 on page 2). These developments will be discussed in detail a subsequent chapter.

But PET is not the only tool involved. Since about 1992, the development of functional magnetic resonance imaging technology, (fMRI, the use of an MRI scanner to measure 'function') has also changed the above picture. fMRI scanners are more common than PET scanners, since they are more widely used for clinical imaging, and less expensive to run. The possibility of doing brain mapping studies has therefore been extended to many more centres, leading to a new kind of competition in the field. Some PET users have expressed fears of a band-wagon of imaging studies done by non-experts in functional imaging, while the 'death of PET' was also pronounced--fMRI does not require a cyclotron, and is considered less invasive than PET scanners which require the administration of radioactive substances to subjects. Other tools have been brought under the label of brain mapping technologies since the mid-nineties; the latest Human Brain Mapping Conference Brain Mapping course dedicated time to fMRI, PET, trans-cranial magnetic stimulation, MEG and EEG, and 'anatomy' as key components of the brain mapping armamentarium.

Indeed, a common practice in the use of these many technologies is that they are variously combined to provide representations of both activity and structure. The results of multiple tools are combined to produce complex objects. Maps of activity in the brain are therefore often produced by merging types of data from different sources. Even with a single technology, diversity can also be observed in terms of scanners and software used. Even before other technologies were included in mapping, throughout the eighties PET scanners could be considered 'little big science', with no two scanners and cyclotrons being the same. Until the release of 'packages of programmes' for data analysis, the software used was also quite diverse. In addition, PET is usually employed in combination with other imaging technologies (CT or MRI), and combinations may differ per institution. Furthermore, because of the costs and complexity of purchasing and running the scanners (Frick et al., 1992), alliances with several research and clinical groups have been the rule, so that no two centres have had similar overall composition and research agendas.

Around these research activities, a recently formed community shows some of the earliest traditional signs of 'professionalization' or discipline formation. The International Conference on Functional Mapping of the Human Brain has been held since 1995, when the first conference was organised as a satellite meeting of the Society for Cerebral Blood Flow and Metabolism. Two journals have been set up and oriented to publishing brain mapping research*: Human Brain Mapping* (1993) and *NeuroImage* (1992). The publications of monographs and textbooks on brain mapping is also quite recent. Besides Images of Mind, published as a Scientific American Paperback (1994, 1997), and addressed to "a broad audience", other textbooks on brain mapping appeared in the nineties. Yet, a great amount of diversity remains in many aspects of this research, and up to the late nineties, the Association has been deliberately 'conservative' in its activities, concentrating on organising the yearly meeting and course. Disciplinarily, almost no one has been 'trained' in this 'field' (Fox, 1993), and large interdisciplinary teams are involved in running experiments-- motley crews of physicists, statisticians, psychologists, neurologists, etc.

A Focus on Representations

It is therefore difficult to speak of functional imaging research as a speciality or discipline during this period, or to trace its development according to a single technology or research area. The object it examines is also contested, as discussed above. A thread linking various developments can be found, however, by considering these developments as the constitution of brain mapping as a representing practice. The importance of building and sharing representations can be seen at many levels of functional imaging work and its importance is stressed by participants. For example, the growth of this stream of research was recently evaluated using citation-analysis, which takes a shared representational convention as an indicator of work done in the field. (See Figure 2). From the point of view of the editor of *Human Brain Mapping*, having a reference to Talairach atlases means working on the topic of brain mapping.

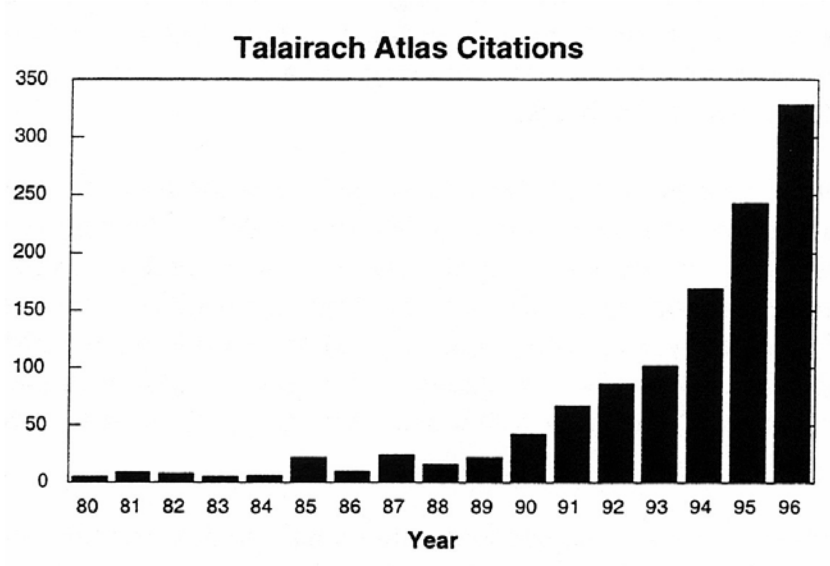

Figure 2 Talairach as shared convention in the field.

Reproduced from ICBM (1997).

There is very little ‘wet’ work in brain imaging: human subjects appear briefly, for a few hours at specific times, and the manipulation, analysis and interpretation of representations form the overwhelming majority of the work performed in the lab.In terms of the work performed in the lab (‘what functional imagers work with’) Annex 1 contains my account of discovering the importance of representations through fieldwork.

Another sign of the importance of representations can be found in discussions and reviews of journals in which functional imaging research is to be disseminated. The editor of *NeuroImage* promises attention to representations:

> “The care we give to reviewing, typesetting, and producing the manuscripts will be surpassed only by our commitment to visual integrity of the illustrations (Toga, 1992).“

In the same vein, reviewers of journals evaluate the ability of journals to carry the representations produced in this research--whether colour images can be reproduced, whether authors are charged for these and what the quality of representations are (Cohen, 1997) . For reviewers, the claims of brain mappers are best supported when journals can render colour maps, the representations in which these claims are embedded:

> “The large format and high-quality reproduction allow the dramatic colour images-a hallmark of the field-to be shown to magnificent effect (Haxby, 1995) [reviewing *Human Brain Mapping*].”

The corollary of this alignment between a material support that accommodates the elaborate representations and brain mapping research also holds. When the production values praised above are not included in a journal’s profile, then this is taken to exclude brain mapping investigations. A reviewer of a new journal on “laterality” assumes that the journal will favour the “phenomenology of laterality” and “speculations about its neurobiological underpinnings”, rather than clinical work and imaging studies:

> “This inclination is reflected in the small format of the journal (which precludes the large glossy figures that are now routine for imaging studies) ((Purves & White, 1995)”

Representations are therefore acknowledged as important for the field itself, in terms of making and sharing its object(s) of research. The importance of developing representations and conventions for making and interpreting them will be shown in detail in subsequent chapters.

Undoubtedly, representations permeate all scientific work in the modern period (Latour, 1990)(Lynch, 1990); a focus on representations and inscriptions in science studies purports to make the dynamics of Western scientific work and its successes visible. The argument I am making here takes representations as a starting point in a slightly different way; it takes representations to be important for understanding brain mapping work in particular. In a community-in-formation, where the material and institutional conditions vary, where various disciplines interact, and where the scope of the common project of ‘mapping the mind’ is far from settled, researchers recognise each other’s work in terms of the representations produced, evaluating their own successes in terms of their ability to produce maps and to have their results circulate in terms of representations in journal and databases.

Representation will be examined as a communal socio-technical activity, not primarily as an individualised, private cognitive one. Looking at representations is a way to get insight into the conventions of a group: into its “instruments, graphic inscriptions and inscriptional processes” (Lynch, 1990). Representations form the empirical materials obtained through imaging technologies (scans), the experimental strategies and knowledge claims (maps), define the epistemics of functional imagers (their view of what they do) and are part of strategies for establishing brain mapping as important in neuroscience and clinical settings (atlases).

The few markers of development of this community discussed above point to the large investments in representational techniques that provide brain mappers with their object. But, to recast Hacking’s (Hacking, 1983) terms, researchers do not want to be seen to be only ‘representing’, in the sense of passively observing, but as also ‘intervening’, experimenting with the brain and mind. Their object of study, being so powerfully visually representational, is the source of anxiety. A search for ways to overcome this, by highlighting the search for principles of brain organisation rather than maps as representations, is a growing concern in recent brain mapping research (Friston, 1998). Furthermore, the central role of representations in this work underlies an important tension in brain mapping research, which will be addressed in detail in a later chapter.

Representations therefore constitute a central activity and characterizing feature of this stream of research. Brain mapping can be seen as a new arrangement for seeing, an emerging techno-scientific project in which representations play a key role. But while it serves here as a valuable unit of analysis, the notion of representation does not have explanatory power in and of itself. Why are representations such an important part of the process and outcome of this research? How do they become so important in effecting changes in notions of mind and brain? While taking representations as motif in the rest of this book, I will be making the argument that they are shaped by two intertwined processes: biologisation and the informational turn.

Bodies and Bits Entwined: the argument about the epistemics of representations in brain mapping

Brain mapping, as a new high tech arrangement for seeing inside the body, relies on representations that inscribe notions of mind onto the body (biologisation). These representations are effective because of the mobilisation of a set of technologies and manipulations involving complex digital spaces (informational turn). Each process will be discussed here separately, in terms of the intellectual traditions that have construed them as categories for analysis. In subsequent chapters, each of which deals with a different representation in brain mapping, they will be discussed as inseparable and interacting dynamics.

Self, Embodiment and Biologisation

Many scholars have analysed the ways in which the body is explored and marked, and made into the locus of power in modern and post-modern culture. Complex interactions between the creation of new objects of scientific study, new institutional arrangements and new modes of 'governmentality' often revolve around the constitution of representations. Brain mapping, as a new stream of research, produces representations which recasts understandings of the social and the somatic, and of the mental and the physical. Phrases used to describe brain mapping research, like "mapping thoughts", "the mind in action", or "the biology of madness" point to brain-based conceptions of mind and its diseases--arguably, formulations which contrast with the more psycho-dynamic views which were dominant just two or three decades ago. The emphasis on finding new physical traces of the mind therefore inscribes brain mapping in a process of biologisation. This shift resonates beyond the disciplines (psychology and neuroscience) which have mind and brain as their objects. When mind is linked to the brain, this object of study is accompanied by shifts in these notions of self and mental illness. As the mind comes to be known through the body in novel ways, then a different configuration of the self arises, with a different relation to systems of knowledge and power (Dumit, 2004).

Many analyses that address the recasting of social relations in terms of the body have been inspired by Foucault's work on the relation between knowledge and institutions for (clinical) medicine, the penal and military systems or the management of insanity (Foucault, 1976; Foucault, 1976). A common theme in this body of work has been to analyse the move to embodiment. This can mean inscribing onto the body the regimens of health, hygiene, military discipline, morality, as well as dysfunctional opposites: disease, insanity and inefficiency. Measurements of heights, strengths, weights, temperatures, speeds, and shapes of large numbers of conscripts, workers or patients have led to particular understandings of normality and abnormality. Thus, the argument goes, difference came to be a mark of the body at the end of the 19^{th} century, "the somatic territorializing of deviance" as Urla and Terry have coined it (Terry & Urla, 1995). Such critiques sometimes posit embodiment as essentially problematic (more on that below). But for the purpose of the argument developed in this book, the strength of this approach lies in highlighting the link between the body and the social, between the individual and populations, through the constitution of representations:

> "…what we know to be bodies are always representations; what matters is that scientific and popular modes of representing bodies are never innocent but always tie bodies to larger systems of knowledge production and indeed, to material and social inequality (Terry & Urla, 1995)."

Systems of knowledge differ, however, and this has consequences for the ways bodies are involved in them. Arguably, systems of knowledge are becoming larger and more heterogeneous, with the consequence that the biological is increasingly used to define relations in social systems (Rabinow, ; van Dijck, 1995). The Human Genome Project and molecular biology have been analysed as a particular kind of biologisation, namely geneticisation. Geneticisation transforms not only social relations in terms of biological definitions but also generates modes of social interaction based on biology, what Rabinow has termed bio-sociality. In this context, there is a partial

> "move away from face-to-face surveillance of individuals and groups known to be dangerous or ill, … toward projecting risk factors that deconstruct and reconstruct the individual or group subject. This new mode anticipates possible loci of dangerous irruptions through the identification of sites statistically locatable in relation to norms and means (Rabinow, 1992)."

The use of formal and bureaucratic tools (surveys, files, tests) are an important component of this process, which is "non-subjective in a double sense: it is objectively arrived at, and does not apply to, a subject in anything like the older sense of the word (that is, the suffering, meaningfully situated integrator of social, historical and bodily experiences) (Rabinow, 1992). " This has been termed the "technocratic administration of difference" (Castel, 1981), which focuses on sets of factors which it represents and finds in/significant. The point in terms of the body is that the activities that constitute it as individual tell as much about social arrangements, as they do about individual circumstances. Furthermore, this relation of the body to the social may increasingly be determining these individual circumstances, in a culture where biomedical identities are crucial and where bodies come to be known via information processing technologies (Dumit, 2004; Thurtle, 2002).

While having blossomed into a large area of academic inquiry, the theoretical and analytical moves that examine 'the embodied subject' seem to lead to a conundrum. Not that odd juxtapositions do not have their place in beginning-of-millennium theorising; purity is no longer a criterion. But, coherence, if not purity, might be a reasonable goal; paradoxes may still be preferable to contradictions. The question can then be posed as follows: How does one perform a critique of such a move to post-disciplinary or post-modern notions of the body, if bodies in modern society are said to be properly understood as representations? Constructivism, because it rejects the possibility of an un-represented body, has often been accused of being incapable of such evaluative assessments. How is it possible to make the constructivist point that bodies are made and unmade as representations, while also maintaining a sense of what is gained and what is lost in the various configurations of modes of representation? In other words, how can a notion of the body or of the self (on which such a critique would rely) be maintained, without appealing to unmediated versions of these, since this would imply finding the body outside representation and technology… Van der Ploeg (van der Ploeg, 1998) suggests a metaphor to understand the relation between these registers. Modernist notions of self and post-modernist moves towards multiplicity, diffuseness and a breakdown of boundaries (human/animal, biological/material, etc) can be seen as two sides of a coin. By taking both stances as inseparable, the notions of normal bodies can be critiqued as having served to maintain Subjective Western Man, and never having existed in nature to start with. The way deviance from this model is established can also be shown to marginalize and disenfranchise 'others' from full participation in the state as citizens, in the market as labourers or owners, or as possessing a fully-fledged autonomous self.

At the same time, it is also possible to view post-modernity as a co-existing, alternative discourse that proposes powerful positions. These are appearing 'kitty corner' from regular bodies, as the institutions that sustained and were sustained by Man are pulled, bent and otherwise exploded out of their original shape by the new configurations of world economies, cyberculture, coalition politics and enhanced bodies that go from substandard ('handicapped') to better than most (Haraway, 1991). In such a world, flexible bodily boundaries, inchoate personhood and multiple alignments may be better ways to gain access and exercise power than the proper correspondence to the norm. But, from a pragmatically political perspective, Van der Ploeg (1998) makes the powerful point that if only those traditionally excluded from notions of personhood take up the labels of post-modernism, this may not challenge the categories used by those currently in power and simply dissolve any political action that was arising at the margins.

In other words, the question posed here is how to avoid the conundrum of oppositional discourse that appeals to a romantic notion of the natural body, in order to critique an institutionalised one. Van der Ploeg provides a philosophical answer: Post-modernism can serve as a powerful stance to highlight what and who is excluded. And while the contingency of representations of the body itself cannot be critiqued, categories of modernism are not powerless because contingent, she reminds us. We are, most of the time, (still) predominantly interpellated by institutions on the basis of modern bodies. From an anthropological point of view, Rayna Rapp (Rapp, 1997) proposes two empirical strategies to solve a similar conundrum in her study of ultrasound: to explore the meanings attached to new technologies by a variety of subjects, and to try to open up the context in which debates are pursued, shifting these debates from medical/scientific framework to a wider cultural/social framework.

The first strategy has been applied to brain mapping in a few studies. Bichard and Cohn have recently embarked on a study of participants in brain scanning experiments (Bichard, 2002). From a more conceptual starting point, Dumit has explored what it means for the category of person to be partly constituted through novel digital imaging of the brain. This analysis reminds us that the stakes are indeed high, when the basis of the self is addressed. Dumit offers this declaration of a biological psychiatrist, whose review of PET research begins with the following words:

> "In the 1970s, the anti-psychiatry movement almost had us…but now we have proof (quoted in (Dumit, 1997)."

With the "proof" provided by PET, biological psychiatry puts anti-psychiatry on trial, and it puts scans of brain function in the witness box. Dumit goes on to note that even in cases when non-biological therapies are valued, they are meaningful in terms of the brain, in the same way pharmaceutical treatments are understood:

> “the brain remains the bearer of mental illness, but has now become an intersection for social and biological influences (Dumit, 1997).”

In brain mapping, the brain is indeed an intersection for therapeutic interventions, and an obligatory point of passage, through which the physiological effects of drugs as well as social and cultural phenomena are to be translated. Other work on the contextual meaning of these images of brain function show a great deal of hope invested in PET scanning, likely means of ‘testing’, and offering the possibility of distinguishing normality from abnormality. The desire for an objective answer to health and disease is focused on the body, and on the ability of technology to provide particularly objective answers (Dumit, 1994)(Beaulieu, 2000). Other meanings of brain scanning, particularly those of cognitive psychologists, neurologists and neuroscientists will be encountered later (especially in chapter 4).

But mainly, this book follows the second strategy suggested by Rapp in order to discuss techno-science and embodiment. Rapp proposes the recasting of debates about technology from a medical/scientific context to include a more socio-cultural one. In addition to questioning what the application of technologies might mean, the analysis I will pursue also problematises how ‘applications’ that show the ‘biological substrates of mind’ are constituted. A number of examples of shifts in categories of mind and brain have already been discussed earlier in this chapter, and will be explored in detail in chapters 3 and 4.

Rather than dealing with technology as black-boxed, the object of a factual description, my own attempt to recast debates about brain mapping will closely follow how various uses of technologies and the knowledge constituted around them have developed. I therefore also draw on the strengths of science studies, which open up the boxes of knowledge and technologies often left closed by other disciplines such as gender studies or medical anthropology.

Technologies of Brain Mapping and the Informational Turn

As noted in the last section, the bio-medical institution is an important dimension to consider, insofar as notions of mind are brought into the realm of the body. The technological context of brain mapping is also very significant. A new set of research practices, in which information and information technologies play a crucial role, is associated with brain mapping’s version of the mind-in-the-brain. The process of biologisation of the mind specific to brain mapping is entwined with the development of a relatively new context for making and using representations. If mind is changing, becoming physical via translation into biological terms that relate it to the brain, the brain is also changing. It is also translated, and comes to be understood, studied and measured in a digital form. In other words, if new representations are powerful in reconfiguring key dichotomies and interventions in mind and brain, this power is constituted in a large part by the possibility of making, correlating and circulating these representations. This is the second dynamic in brain mapping, where digital data and electronic networks play an important role—they are central to the experimental systems of brain mapping

(Rheinberger, 1997). Epistemic objects are at the centre of scientific research practice, and are continually materially redefined to yield interesting results. Because the materiality of these objects has a particular digital character and is attuned to and circulates in electronic networks, the analysis of brain mapping's development hopes to contribute to an analytic framework for understanding the 'informational turn' in a number of areas of scientific research.

The dynamics of the constitution and use of new media constitutes the kind of topic traditionally significant for science studies. This is the case because new media not only become new supports for scientific knowledge, but also offer new possibilities for communication and research. In this case, the changing mediation of scientific work reorganises physical spaces in which it takes place. The consequences of the ensemble of practices and technologies that can be loosely labelled 'the informational turn' will be discussed theoretically here, with emphasis on their relation to representations.

The contours of this shift are only beginning to be sketched in the fields of communication, science and technology studies, and history of science. Two significant elements arise from the work to date and inform the study of the informational turn. The first relates to the need to consider the interactions between technologies, rather than single tools (the pc) or applications (email) (Hagen, 2001; Hine, 2002). The second element is the importance of the interaction between the deployment of technologies, and the knowledge being produced and its uses (Bowker & Star, 1999; Lenoir, 1998; Robins, 1999). Indeed, the very issue of what can be known is raised by new research practices. Work on the biological sciences, where the informational turn has been especially sharp (Kay, 2000), shows how the disciplinary aspirations, and the very epistemics of a field, change as new research practices reliant on information and communication technologies are integrated (Bowker, 2000; Hagen, 2001; Lenoir, 1998). The informational turn implies widespread changes (not simply cumulative, nor simply the 'adoption' of a single tool) and it is assumed that epistemological objects are transformed by these two types of changes-- the role of digital information and the networked character of research (Wouters, Beaulieu, Park, & Scharnhorst, 2002).

The use of tools for the production and manipulation of *digital* data often means that aspects of these processes become quantified, automated, or both. This may in turn lead to the creation of databases and other repositories, and to new types of experiments. This dynamic around digital information is neither inevitable nor identical across the sciences, but it is recognisable. For example, advances in visualisation, databasing, hardware networking and automation all played a role in making (some parts of) biomedicine informational (Lenoir, 1998). These changes are sometimes said to lead to 'data floods', and are followed by calls for yet more tools and infrastructures to manage these developments.

The second aspect of the informational turn is the increasingly *networked* organisation of science, which can be observed in various aspects of research. With regards to the development of research questions, interdisciplinary research, organised around specific problems, is increasingly prominent. Developments in neighbouring fields can also create new links in such networks, as new data repositories or tools become available. For example, in biology, the field of taxonomy embraced bioinformatics via genetics. The availability of sequencing data was especially significant in this process (Hagen, 2001). Not only the research agendas but also the physical place of science may take on a networked character. The laboratory, for example, may be challenged as the exclusive or dominant site of knowledge production, as databases (Lenoir, 2002), electronic discussion lists (Hine, 2002), or web sites (Beaulieu & Simakova, 2002) come to fulfil functions that were traditionally located in the lab, or as new practices arise that are distributed in many sites by their very design (‘collaboratories’) (Finholt, 2002). Communication in science may also rely increasingly on networks mediated by information and communication technologies. Journals may no longer be the primary site for communication about ongoing work or for the dissemination and preservation of findings (G. Bowker, 2000). They may also become so closely entwined with data repositories as to no longer be recognisable as traditional journals (T. Lenoir, 2002). Finally, these various networks may interact, with unanticipated consequences. Data-sharing via databases may interfere with publication practices, and distributed computation in biomedical informatics may play havoc with traditional ethical guidelines for patient protection(Wouters & Schröder, 2003). The informational turn is therefore part of the complex set of practices that shape how representations are constituted in brain mapping research.

Maps as Informational Epistemic Objects

At the core of brain mapping are maps. Maps, in general, are themselves quite complex objects, which articulate various systems of knowledge (Alpers, 1983; Wood, 1993). They often seem to do so objectively, rendering the world as though ‘viewed from nowhere’. For example, political maps coordinate what is known about geography and nation states. To articulate two such different bodies of knowledge in a single representation, maps rely on particular conventions. This is also the case for brain mapping, and indeed, a number of analogies can be drawn between this type of cartography and brain mapping. Various ‘projections’ of the earth exist, which emphasize one hemisphere over the other, or affect the relative size of continents. Similar issues are at play in brain mapping, with different projections of the brain (see Figure 3)

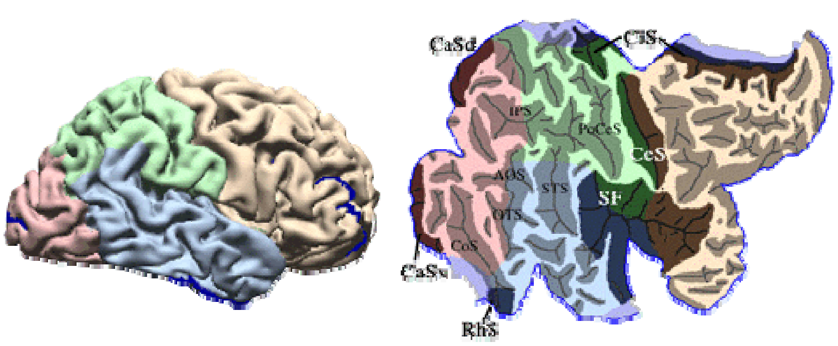

Figure 3 flattened cortex

There have been debates about how best to represent the cortex as a 'volume' or as an unfolded, flat surface, or again as an idealised, inflated sphere (not shown above). These conventions are at times challenged, at times more stable. They are important features that distinguish not only the epistemic objects of different disciplinary traditions, but also correspond to particular sets of tools and technologies, and purposes in brain mapping

Another set of conventions, which can be used to compare geographical maps and those produced in brain mapping, concerns the use of an abstract space. Coordinate systems such as those marking latitudes and longitudes of the earth have also developed in the various projects to map the brain. One of the most influential is that of Talairach, illustrated in Figure 4.

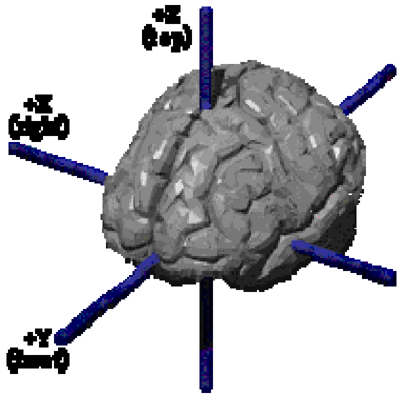

Figure 4 The Talairach system marks each point in the brain using a Cartesian space with x, y , z coordinates.

In brain mapping, the coordinate system has been used to develop a standard space, which serves to compare brains. In this practice, certain variations in individual brains are removed to align the brain scans (or other data) to a certain idealised or standardised brain space. What remains, in principle, are the differences between brains that matter. For example, differences in the overall size of the brain are removed, but relative, proportional differences in size of parts of the brain would remain (see Figure 5). These differences are considered important in exploring how the organisation of the brain relates to anatomical differences of this kind.

Figure 5 Various aspects of one method for transforming brains to a standard space.

The ICBM atlas transformations, which transform the brain to conform to a standard space.

Reproduced by permission from Neuroinformatics.

Finally, a third analogy to terrestrial geography can be found in the way 'atlases' of the brain are being produced (See Figure 6). They serve as both reference tools and as baselines for further investigations in brain mapping.

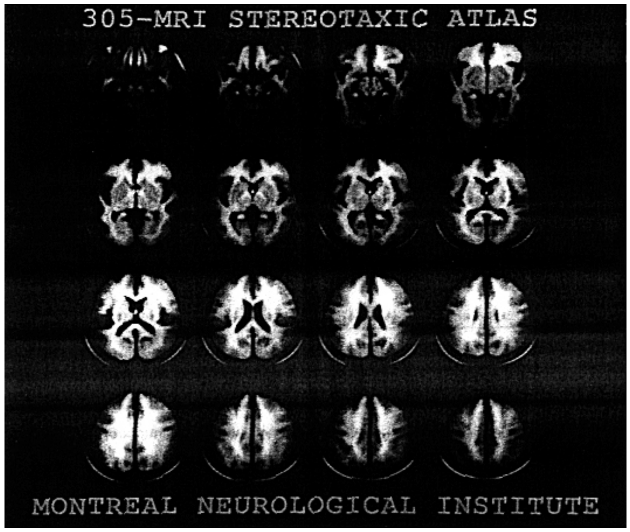

Figure 6 Atlas of the Brain of a Normal Population

Reproduced courtesy of Brain Imaging Centre (BIC), Montreal Neurological Institute

Each of these sets of conventions and representations is the outcome of complex processes of development. For example, the production of an atlas of over 300 MRI scans depends on the possibility of not only comparing, but also compiling all these scans from different subjects. This in turn relies on the development of an acceptable abstract space in which to 'average' these scans. And this abstract space depends on the production of a 3-d volumetric rendering of the brain, and on procedures to make brain comparable. All the conventions illustrated in these last paragraphs are aimed at transforming scans and data about the brain in anatomical terms. A different, but related, set of conventions is used to render functional activity. In figure 1, the functions displayed are isolated by 'subtracting' two functional scans, placed in an abstract space. These scans can also be averaged, using a standard space. Functional data is furthermore correlated to anatomical data using the x, y, z coordinates to organise the various types of data. This brief description sketches how mind comes to be inscribed onto the brain.

Each of the transformations described above involves decisions and constraints about how the brain and mind data are to be dealt with, which aspects of the data will be preserved, what will be eliminated as noise, and how different data will be coordinated. Researchers have developed a number of technologies and tools, and have come to rely on them to produce their epistemic objects. Biologisation and the use of these digital tools are therefore entwined in each of these manipulations and in each of the conventions that direct how they are to be performed. I have glossed here over the debates about each of these procedures, but return to them in the course of the book. The subsequent chapters will return to these manipulations and discuss their development and applications in brain mapping.

For the moment, however, the main point is that these manipulations arise out of a particular technological context, one that developed gradually over time and one in which researchers and funding bodies have invested much time, funding and effort. This is a complex set of tools and practices that goes much beyond the availability of scanners. Significant computer power is needed, since calculations are made for each data point in a scan, as they undergo these transformations. Sophisticated algorithms are used to remove certain features of the data, while maintaining others. And visualisation is an important tool in both rendering this complex data and in combining various types of information into a composite image.

Producing the objects of brain mapping therefore relies on the use of digital technologies to manipulate scans, and on the availability of electronic networks to gather and process them. These representations of the brain function in a setting where computer screens are the most dominant interface to brain mapping's raw material, experiments and knowledge claims, and where manipulations of disks containing data about thousands of scans are some of the most material aspects of experimenting. The biological and the informational aspects in brain mapping are therefore mutually constitutive of these representations. For brain mapping, the production of digital information is closely tied to new technologies. The way they become meaningful, however, is related to the way these digital traces are associated in the course of experiments with traces of the mind and brain. These associations take place in the representational space of the maps.

To summarise the argument so far, brain mapping is considered here as the constitution of a new body of knowledge. Two main aspects are shaping it. First, a new realm of phenomena (mind) are becoming part of the body, and moving into the area of circulation (institutionally) where the body traditionally circulated. Second, the other important aspect of this body knowledge is the digital and electronic features, which are here labelled the informational turn. The digital aspect is important because of the manipulations of data it allows and the epistemics it generates (mathematisation, correlation and manipulation). The electronic networks aspect is important for the circulation in a more conventional way—transport, pipelines, distributed work, promises of efficiency and integration, and the scale of the work that becomes possible. These two aspects interact to create powerful representations, but this interaction is not without tensions. On the one hand, there is a move towards the biological, which has traditionally meant the physical, the material. The informational turn, however, implies the mobilisation of a set of technologies and practices that have more generally been labelled as ‘virtual’. The possible tension between these two dynamics is evoked through the book using the labels of ‘virtual brain’ and the ‘physical mind’, and is discussed explicitly at the end of the book.

Inscriptions

That the manipulation and transformation of representations is a key aspect of scientific work is not an unfamiliar argument to students of science and technology. A major effort in highlighting the importance of representations in scientific practice has been the Latourian notion of inscriptions (Latour, 1984). It aims to provide a correlate to the efficacy of Western science and technology since the Modern period. The powers of the “centres of calculations”, which make up the nodes of networks significant for the shaping of Modern society (science, civil institutions, and medical systems), can be explained by the manner in which they mobilise inscriptions (Latour, 1990).

Inscriptions are particular in that they make ‘mobilisation’ possible. The features that make inscriptions mobilisable are worth considering, since they provide a way of linking practices, institutions and cognitive claims. Inscriptions, Latour argues, are not in and of themselves explanatory, but become so when considered as mobilisable allies, in the sense that they can convince someone to take up a statement, to make it more of a fact or to change one’s behaviours. In the Latourian understanding of inscriptions, two main (Latour, 1990) basis for further work. Modern medicine then, is the shift from “small scale practice to large scale manipulation”, so that:

> the same medical mind will generate totally different knowledge if applied to the bellies, fevers, throats and skins of a few successive patients, or if applied to well kept records of hundreds of written bellies, fevers, throats and skins, all coded in the same way and all synoptically present .

This is the level of analysis where the efficacy argument is most potent, linking practices and achievements. It highlights how, for example, individual brain scans produced in a session can become increasingly significant (in all senses of the term) as they are "cascaded" with others, and once so assembled, can come to stand for a population (see Figure 6). This set of cascaded representations accrues authority, so that it can in turn serve as a diagnostic tool, and so that further individual scans will be made for comparison with this new standard. Alzheimer's patients, or normal males or dyslexics could all be populations whose brains are averaged in this way. The representations are produced in relation to notions about illness and through new combinations or representations, these conditions come to be redefined.

A second main aspect of this theory of inscriptions is the semiotic nature of the circulation of inscriptions as "immutable mobiles." The term is paradoxical enough to point to the difficulties in its use: how can something be the same here and elsewhere, no matter where? This question need not be posed in extreme constructivist mode to leave the analyst perplexed. In that sense, a concept like Star's boundary objects, highly defined in local, individual use, and looser and more flexible in communal use, emphasises the need for more sensitivity to the contexts of inscriptions, while maintaining a focus on circulation (Star & Griesemer, 1989). Establishing communality or stability of meaning is work, an outcome, and not a given of modern inscriptions. This book aims to show how the digitality of representations is given meaning as mapping practices develop, and how contexts are developed so that these representations do become mobile.

But even if inscriptions do not start out as immutable mobiles but rather sometimes end up that way, the features that Latour identifies are useful as categories for an empirical analysis of representations. Some of the features, however, may need to be redefined when dealing with inscriptions in a digital medium. These features can be summed up as the fact that inscriptions are mobile, immutable, and flat, that their scale can be modified, that they can be reproduced at little cost, recombined, superimposed, that they can be part of written text, and rely on optical consistency. These features have important effects, in that they make possible the consolidation of knowledge, its mobility and the very creation of Modern institutions.

The fact that Latour assumes the stability of these features, and the possibility of combined immutability and mobility, is interesting for the argument developed here. Rather than a weakness of the theory, these shortcomings of his descriptions of the features of inscriptions may be pointing to the importance of the techno-social context on which he focuses. Latour ties the effects of inscriptions to the possibilities offered by the technology of the printing press. Furthermore, he is also writing at a point in time when paper-based representations were produced and perceived in highly stable, conventionalised ways. This stability has not always been the case and there are historical contexts where conventions may be absent, highly local and partly destabilised. By returning to the early modern period, inscriptions seem to be in somewhat more turmoil. For example, in Latour's work, inscriptions encompass image, number and text. But these are contested modes (Stafford, 1991), and art historian Barbara Stafford has traced how a hierarchy of modes of representations developed and affected the way visual evidence, in particular, was considered. Because of a distrust of sensory perception, specifically associated with the visual, images were denigrated and largely abandoned in favour of quantitative and textual modes of representation. Inscriptions can therefore belong to a 'genre' and be variously valued. Historian of physics Peter Galison has also considered such distinctions in types of evidence in high energy physics (Galison, 1997).

Indeed, while it would seem that images are inundating contemporary medical culture (Stafford, 1996), the 'visual' is also not a single entity to be translated monolithically into new media. A culturally specified set of practices warrants apprehension of visual evidence by (medical) researchers (Cartwright, 1995). Like the moving image before it, digital images may be associated with new visual cultures. In the case of digital images, the conventions that make them into valuable inscriptions may contrast with those produced on paper with a printing press, and they may not yet be as stabilised. For example, the possibility of combining inscriptions is attributed to optical consistency. Yet, in the case of digitised imaging, it is not so much the straightforwardly geometric relationship of Renaissance perspectival drawing that determines the combinability of scans. With digital imaging, the visual becomes quantitative, and traditional notions of perspective based on the observer are exploded (Kember, 1991; Kember, 1998). It is therefore interesting to investigate empirically the relation of new technologies, such as computers and electronic networks, to these effects. New technologies may reshape the features of inscriptions, making some more significant, or less relevant.

When approached empirically, Latour's features of immutable mobiles therefore highlight significant points of debate in the developing representational practice that is brain mapping. With a new technology come different affordances. With a growing investment in these, they develop and allow new manipulations, while, again requiring new technological and institutional arrangements. Without attributing essential properties to the medium, it is clear that while digital inscriptions share some of these features, they can also function differently than paper-based inscriptions. These features are therefore taken as categories of empirical enquiry, rather than as stable features of all inscriptions.

Digitalism and Opticism

If features turn out to be different, the effects of insciptions may also contrast between types of inscriptions. There is therefore the need to be sensitive to the potential of new technologies for the function of inscriptions, without reifying what the digital might mean. The use of digital tools can lead to a particular configuration of epistemology, representation, and laboratory work, as discussed in Michael Lynch's work on topical spaces (Lynch, 1991). A topical space is both a symbolic and physically constituted space that is articulated in relation to technological organisation. Such an analysis ties an epistemological framework to a particular topical space. In other words, by being able to analyse a particular site of knowledge production, in its symbolic and physical features (which are affected by the technological organisation of the site), the very knowledge that emerges can be characterised.

Lynch's starting point is the context of knowledge: where is the lab? And how does the space of the lab organise knowledge? In answering this, two orders of spaces are distinguished and discussed by Lynch, opticism and digitalism. These are worth considering in some detail here, since they demonstrate how new technological possibilities and new representations might be linked, to discuss the context of knowledge about the brain. Lynch is not interested so much in the epistemological essence of knowing, as in the scripts that may be embedded in opticism: “what it expresses is 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 systems (Lynch, 1991).” Thus, opticism coordinates spaces and practices: optical instruments based on the technology of the lens, representational technologies, and a theory of optics (Lynch, 1991). All these are part of a way of organising, conceiving and articulating the relations between the subject and the object. For brain mapping, the dissections and cellular explorations of neuroanatomists are produced within and opticist context, since they are based on perception and observation.

In contrast, a digital space is pixelated rather than constituted according to rays that relate fields of vision to the ocular apparatus. This means that digital space is mathematised, with important consequences for mechanical and automated manipulation. The details of brain scans are therefore eminently manipulable. Order in digital spaces emerges from a ‘play of signs’ rather than from resemblance. In brain mapping, this implemented in the possibility of measuring similarity (as in the twins brain experiment mentioned earlier), rather than relying on visual evaluation by an embodied expert.

Thus, following Lynch, digitalism is an explicitly simulated or constructed space. Phenomena in a digital context are not contained in a particular representation; research scans do not have the status of snapshots in this digitised world, but are constantly recreated in the processing of digital data. While ‘construction’ of representations may be more evident, this does not mean that any and all constructions are possible. Given the importance of representations for brain mapping, the notions of digitalism and opticism are valuable starting points in analysing a scientific practice that relies so heavily on organising and presenting ‘traces’. Therefore, the digitalisation of representations of the brain will be analysed, using Latour’s features of inscriptions as fruitful categories of empirical analysis, and Lynch’s ‘digitalism’ as a framework for understanding how a different order of work (ranging from the epistemological to representational) might arise, and how these digital inscriptions might have different effects.

Dimensions of Representations: the outline of the book

“A new visual culture redefines both what it is to see and what there is to see (Latour, 1990).”

Representations in brain mapping will therefore be used to trace how experimental practices showing brain and mind develop and how the uses of technologies change in relation to these new representations. Representational practices evolve as the result of processes; interdisciplinary collaborations, the growth of digital technologies, and the visual aspects of these investigations will be shown to have particular impact on the new objects and practices that arise from this new stream of research. I will also highlight the particular contexts in which these representations have become ubiquitous and the constitution of frameworks in which mind and brain can be translated into powerful representations. Ultimately, my goal is to contribute to an understanding of ongoing shifts in systems (of healthcare, justice and education) that have relied on a different parcellation of what is meant by labels such as mind and brain, although addressing these in detail is beyond the scope of the present project.

Each chapter focuses on a particular kind of representation and on the issues of scientific knowledge and practice it raises. These can be take to correspond to 'scans' and the need to develop ways for nature to speak through technology; 'maps' and the question of method for mind-brain correlations; the 'visual as empirical basis' and discipline formation; 'atlases' and normative interventions. If there is a direction of representations in this thesis, it is a social and technical one, like the movement of an assembly line (Lynch & Woolgar, 1990). Indeed, encounters with 'originals'--the 'optical', the 'patient' in the flesh, the 'real work' of scientists--also spring up in chapter 5. Each chapter is therefore not to be read as a move further 'away' from an original, but to more complex manipulations and translations.

The next two chapters will address shifts in the understanding of brain and mind through the development of scanning and mapping conventions. These chapters specifically take up the interactions between digitalisation and biologisation, looking at how scans become meaningful traces, and come to stand as maps of the mind-in-the-brain. Chapter 2 contains a discussion of the many strategies used by different researchers, in the course of the eighties, to establish what can be learned from scans, focusing on the biological and digital contexts of reference used to ground the data provided by PET. Chapter 3 shows how mapping becomes both an experimental strategy and an organising metaphor for discovering the mind in a new space. The next chapter focuses on the development of a hybrid epistemic culture particular to brain mappers; the result of the integration of quantitative and visuo-spatial approaches to the brain and mind, constituting a quantitative visual culture. Chapter 5 considers how representations developed in brain mapping are cascaded in particular ways, constituting a new kind of mutable mobile. This enables brain mapping to occupy an increasingly significant place in neuroscience and a new normativity to develop around scanning and mapping. The concluding chapter contains reflections on the new features of knowledge developing around brain mapping, and how these might compare to other projects where biologisation and digitalisation figure prominently. The book ends with reflections on how to pursue further analyses of the informational turn in science.

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