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ABSTRACT In the 1990s, the 'Decade of the Brain', a number of digital and electronic resources have been created to enable the rationalization and integration of the various sub-fields of neuroscience. This approach has been described as 'neuroinformatics'. An important subset of tools (atlases of the brain) developed in the Human Brain Project is examined in detail in order to understand how the use of these tools changes the practice of science. In the course of the development of atlases, what constitutes 'objective' neuroscientific knowledge is redefined in important ways, according to both technological possibilities built into these tools and to the constraints of standardization inherent in projects that involve multiple measurements. The constitution of objectivity is examined across a number of levels (ontological, epistemic, pragmatic) and the concept of 'digital objectivity' is suggested as a label for a particular configuration of ideals, techniques and objects of knowledge in cyberscience.

Keywords atlas, cyberscience, database, neuroinformatics, objectivity, social informatics

Voxels in the Brain:

Neuroscience, Informatics and Changing Notions of Objectivity

Anne Beaulieu

> The Human Brain Project may be more important for what it reveals about the behaviour of neuroscientists than the neuroscience of behaviour.
>
> Dominic Purpura
> (Annual Meeting, Society for Neuroscience, November 1993)

What will save neuroscience? Neuroinformatics, of course! [1] This question and its answer are at the heart of a new approach to research involving the use of digital and electronic tools for neuroscience. Neuroinformatics has developed in the course of the 1990s, largely under the aegis of the US-led Human Brain Project (HBP), a large-scale initiative developed as part of the American 'Decade of the Brain'.[2] The HBP has proposed guidelines for a neuroinformatics approach to the study of the brain, stressing the integration of neuroscience and informatics.[3]

Rather than simply urging the greater use of computers as technical support for existing processes and standards, these developments represent

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a particular configuration of goals and practices, pointing to a new approach to scientific work, sometimes called 'cyberscience'.[4] Such developments, where scientific activities are to rely on informatics, are also found in other fields – neuroscientists were not the only ones addressing the need or desirability to develop databases and electronic resources around the turn of the last decade. Other communities (as diverse as oceanography, geography, physics and molecular biology) were also considering the usefulness of such tools, most frequently in terms of databases or of 'collaboratories', as a radically new way of pursuing science in geographically disperse locations.[5] Indeed, early consultations that led to the HBP involved researchers who had participated in projects like LandSat and the Human Genome Project, as well as computer scientists participating in the American Defense Mapping Agency Program.[6]

Different fields, unsurprisingly, have formed different kinds of relationship to new technologies, and have experienced contrasting levels of centralized intervention and management. For example, in a recent document by the OECD Megascience Forum, members of the working group on biological informatics focused on biodiversity databases and neuroinformatics as key areas, noting that while informatics are also important to genetics, 'genomics' had already received much attention.[7] Similarly, the rationale for using informatics also varies from context to context, and may at times seem 'top-down' or user-led (see below, and note 34). Furthermore, what is understood under the label of new technologies represents a varied assortment of tools, ranging from electronic networks to digital models and databases. Finally, the changes brought about by the integration of technology are also diverse: reconfigurations of research practices, authorship, intellectual property and patterns of collaboration have all been noted, usually in relation to a specific aspect of scientific practice or to a specific field.[8]

Thus studies of cyberscience have up to now examined how new objects arise, examined the constitution of data structures, or investigated how scientific work is changed by new technologies. These studies provide valuable insights and are reviewed below. Indeed, approaches to the study of cyberscience will need to vary according to the digital and electronic resources in question – perhaps most consistent (in science studies and social informatics alike) has been the argument that tool-based approaches, insensitive to use or context, are quite limited in their usefulness.[9] In addition, empirical studies of various sciences have shown that analyses of tools should also reflect on the particular disciplines in which they are developed.[10] These points are well taken, and form an important part of the analytic approach in this paper. Cyberscience can be characterized as a novel, technologically-supported organization of knowledge and knowledge-production, in which the digital format and electronic transmission of data figure prominently. I propose here another approach to cyberscience which acknowledges that current databasing and networking efforts cross disciplinary and institutional boundaries,[11] and that the integration of tools in these new research practices may mean that the distinction between types of tools (say, between databases and models) and between activities (like representing and analysing) may be difficult to draw. I therefore propose to look at the case of cyberscience in terms of its style of organization and validation of knowledge.

To frame this approach, studies of the organization of knowledge and the interactions of knowledge and technologies (rather than studies of specific tools) are most relevant. Geoffrey Bowker and Leigh Star have identified three key levels at which a classification, as a formal organization of knowledge, can be analysed. A classification can be read as a text; or it can be analysed as to the way it structures data, and in relation to the way it articulates work practices of those who use it.[12] These three levels capture the 'contents' of atlases, but also the ways in which the building of classification has an impact on the further production of knowledge, as well as on the use of such classification. The importance of computerization or digitalization, however, is not a central theme in Bowker and Star's book. Other studies, however, have addressed these aspects of the organization of knowledge, and give more prominence to the digital technologies and electronic tools used to constitute them.

A number of new objects, produced through the use of digital tools, have been analysed. The concomitant rise of NASA images of the earth and of the new global environmental concerns illustrates one such bind: new objects and new objections are inseparable from the new technologies that sustain them, yet there tends to be very little accountability for the ways in which technologies are developed. Donna Haraway has contrasted a number of objects (race, foetuses, genes) found both within and outside digital contexts, and notes that, paradoxically, both everything and nothing has changed through this digitalization. The 'god trick' persists; our technoscientific investments are still partial and still claim to be total.[13] Catherine Waldby's analysis of the Visible Human Project is a further demonstration that the production of 'a demonstrative visual text', the turning of flesh into (visual) data, is part of a long scientific tradition that evacuates messy bodies.[14] Indeed, the production of digitized bodies seems an especially poignant topic, when high-tech wizardry that floats in and out and through bodies seems to make light of concerns about subjective embodiment – the contrast to humanist projects of emancipation through bodily integrity can be shocking indeed.[15]

To understand why these new objects look the way they do, however, it is important to look at the machineries put in place to produce them. In this vein, the work of Geoffrey Bowker is important in highlighting how new ontologies are 'performed' by digital data structures. Biodiversity, for example, is shaped by what counts for inclusion in the databases, and by how species are to be incorporated in the fields of the databases. Bowker shows how biodiversity databases can be performative at concrete levels, such as the structuring of 'fields' in a database. Databases can also perform more abstract work, such as shaping relations between disciplines – for example, as diverse types of data are entered into a database, the structure of the database will privilege the structure of data coming from particular (dominant) disciplines.

Though such data infrastructure may cause some 'hardening of the categories' (a point to which I will return in my conclusions), neither categories nor technologies brought in to answer calls to unify and standardize can bypass all local settings. Such machineries, though they be formal, still need to be enacted. Linda Hogle's work on organ donation highlights how meanings of individuals' lives impinge, sometimes paradoxically, on the objective descriptions that should unequivocally qualify (or disqualify) bodies as donors. Lives lived, kinds of deaths and kinship relations, find their way into medical personnel's interpretations of the suitability of bodies.[16] Local contingencies interact with formal categories to produce outcomes which might not be predicted from a study of the formal structuring of information. These findings point to the need to analyse how information is valued, as well as how it is ordered. In my analysis of atlases of the brain, I will consider objectivity not only as produced by structures and implemented in technologies, but also as an ideal, which informs further developments – and, at times, a very potent one.

Besides the intersection of digital tools with ontological and epistemic concerns, the practice of science in a digital context also warrants attention. Computers and digital tools reconfigure work, whether they be the result of celebratory attempts to streamline and rationalize certain practices, or to discipline them into a scientific ethos. Marc Berg's work on post-war medicine, and the calls for its rationalization and standardization, demonstrates how, in the process of being rationalized, the work of medicine is also transformed.[17] In other fields, as databases and datamining of sequences increase, scientists see their work shifting from 'wet' experiments in the lab to onscreen work. This is changing the kind of 'labour' involved and, in the view of some scientists, constituting a 'paradigm shift'.[18]

Representations, Ways of Knowing and Tools of Objective Knowledge

In the analysis that follows, I attempt to cut across these distinct levels of objects, modes of knowledge and work practices, by focussing on the notion of objectivity. By taking a concept that is enacted at each of these levels, this approach highlights the mutual constitutions of new objects and new ways of knowing in relation to the large-scale implementation of digital and electronic resources in neuroscience. Specifically, I consider the development of atlases of the brain, which are both objects of knowledge and tools used in research practices. Atlases are repositories and enforcers of objectivity – a concept that dances (like its scheming twin normativity) on the border between what we know to exist and how we ought to know it. In the conclusion, I will argue that digital objectivity may constitute a particular version of this dialectic, shaping the way each constructs the other. Specifically, I hope to highlight the way digital technologies may serve as a powerful interface between various techniques, and that this interfacing may entail a convergence of ways of producing knowledge in various settings. I have as a goal, not the formulation of essential features of digital technologies, but rather their characterization in relation to objectivity as a complex of technologies, such as that which Michael Lynch explores in relation to the constitution of *a space of knowledge*.[19] By taking a definition of informatics to be the material, technological, economic and social structures that make the information age possible,[20] I propose to consider in some detail an important set of neuroscientific tools which has been reshaped by neuroinformatics, namely, atlases of the brain, and show how the digital might be associated with a particular *ideal of knowledge*.

The use of informatics changes the structure and content of atlases, with particular consequences on the representation of objective knowledge about the brain. Most important for the argument developed here, however, is that atlases are meant to represent objective knowledge, a notion that might also be transformed by an informatics context. As normative instruments, atlases shape and are shaped by ideals of objectivity. As Lorraine Daston and Peter Galison demonstrate, atlases are always carefully (though not always explicitly) selective, in order to be objective.[21]

Generally, however, selectivity has been considered not only necessary but also desirable. The removal of the subjective provides protection against imposing aesthetic, moral or theoretical elements on the phenomenon studied. However, the way atlases are selective differs, and Daston and Galison further identify three basic modes of objectivity (effectively, three modes of representation) in the paper atlases they survey: the ideal (a perfect, unblemished type), the characteristic (showing a representative individual) and the individual (naturalistically presented).[22]

In each case, elements of 'raw' nature are selected and represented, so as to satisfy historically contingent notions of how best to achieve objectivity. The selection involved can be that of an expert whose judgement is trusted, and whose name is often borne by the atlas. Such atlases can be found in anatomy (for example, Vesalius' *De Fabrica*), or in neuroanatomy (Brodmann's or Talairach's atlases). Alternately, the selection of what to represent in an atlas can be based on 'mechanical objectivity', which bypasses judgement and human tendencies to deviate, embellish or vary.[23] To adopt mechanical objectivity is to restrain the expert's embodied judgement and delegate the task to a technology, such as the camera, or the brain scanner. This last mode will be shown to be part of the making of brain atlases, through the use of the automated representational power of imaging technologies.[24] But while there is an overlap with the modes of objectivity associated with photographic technologies, digital technologies introduce new elements of control and restraint in achieving objectivity.

Among neuroinformatics resources,[25] atlases are a particularly interesting subset of tools to examine, since their use was well established long before the HBP. They have traditionally been key tools for neuroanatomy; they are used in research and clinical settings and, as reference works, they embody authoritative scientific knowledge. Furthermore, a focus on brain atlases, which are widely used for brain mapping, highlights how this new field of neuroscience has been central to both technological and scientific developments in the HBP. Brain mapping is often described as intrinsically interdisciplinary, and credited with fuelling the growing interest in functional anatomy, and the use of computer graphics to organize knowledge about it.[26] As well, brain mapping's colourful brains have also been central to the popular discourse of the Decade of the Brain.[27] Atlases are therefore highly visible and important tools on a number of levels and for a number of constituencies.

In the 1990s, neuroinformatics atlases were therefore built by drawing partly on existing research in the imaging and mapping community. Better atlases were needed to pursue brain-mapping studies, where scans of brain activity were to be correlated with anatomical information, creating maps of the brain in action. Brain-mapping research had been the context of new applications of traditional paper atlases, especially that of Jean Talairach.[28] A number of research groups had already made efforts to improve on the contents of the atlases, and to improve and standardize the way in which researchers would compare a given case with the atlas. For the Positron Emission Tomography (PET) community, developing better atlases was seen as a way of reinforcing PET results, and the suggestion that atlases based on Magnetic Resonance Imaging (MRI) scans should be developed was taken up as a resolution of a series of workshops held in the 1980s.[29] While atlases were already available as digital tools (often as digitized versions of paper atlases), much more was made of the digital potential of these tools as they developed within a neuroinformatics approach. In the 1990s, atlases acquired other functions, as building new atlases became part of the agenda of the Human Brain Project. The way the HBP came to promote the active integration of digital and electronic tools in research, and to champion a centralized coordination of these efforts,[30] is an essential element to understanding the new functions these atlases were meant to fulfil, and the impact of these on notions of objectivity.

Saving Neuroscience: The Threat and the Solution

Atlases were developed in a policy context that stressed not only the value of neuroscience, but also the need to intervene at the level of knowledge management on a large scale. Many countries declared the 1990s to be the Decade of the Brain,[31] although what this meant in terms of research agendas varied across regions. Whereas European science policy-makers focused their efforts on creating a 'critical mass' of neuroscientists, American concerns did not focus on 'brain drain' issues, but rather on the fact that neuroscience was becoming 'critically massive'. Leading researchers consulted by official bodies (NIH and NIMH) attributed the state of neuroscience and its recent rapid progress to advances in molecular biology, imaging, neurobiology and computational power.[32] While noting that the successes of neurosciences rightly warranted public attention and recognition, neuroscientists and policy-makers also worried that the wealth of available data was becoming the source of a crisis in neuroscience.

This crisis was defined as an 'explosion of data', or a flood, deluge, glut of information, avalanche, overload, and so on.[33] This crisis affected both the individual researchers and the field, and various kinds of solutions were proposed.[34] The following scenario was often cited, echoed or paraphrased:

> Brain and behavioral research has exploded in the past 2 decades because of the conceptual links that were made across different species, levels of biological organization and methodological approaches and links that were made internationally.

But this has led to specialization and decreased ability to relate to other findings:

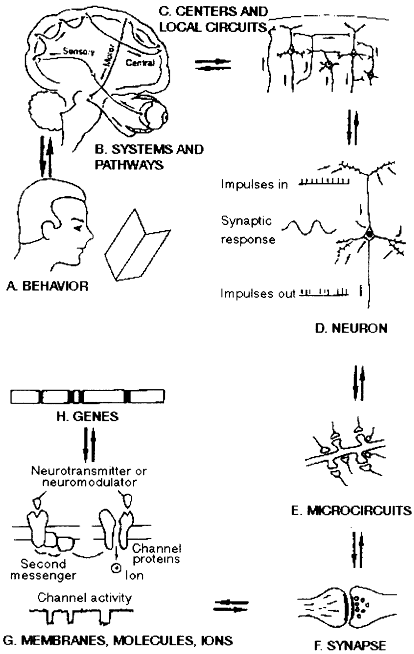
> Thus, an overload of information is threatening the very fuel that has driven brain and behavioral research to the forefront of science.[35]

The solutions that dominated discussions involved the use of digital and electronic tools in neuroscience – neuroinformatics. This proposal for the use of computers had been made repeatedly, in the 1970s, '80s and throughout the '90s, too.[36] But it is a view that seemed to appeal particularly at the end of the 1980s, when plans for new resources for the neurosciences were elaborated under the aegis of a number of American Federal agencies.[37]

Officials at the Institute of Medicine and members of the committee believed that the efforts would yield great improvements in the way neuroscientific research was pursued, since databases would enable hypotheses to be tested with the models to be developed, and new knowledge would arise from querying the databases. Furthermore, the pursuit of 'missing' knowledge would be rationalized, as shortcomings would be highlighted and duplications avoided.[38] The 'translation' of neuroscientific research to clinically relevant knowledge was also to be reinforced by neuroinformatics.[39] The neurosciences were therefore to be integrated through information technologies closely related and developed specifically for the neurosciences. In these reports, ideals of research management, efficiency and the rational pursuit of knowledge all came together around electronic and digital tools, these issues being transposed into a problem for which a technological fix might be provided – a neuroinformatics solution to the exploding information which kept the sub-fields of neurosciences from working together.

This is only a short sketch of the many reports, consultations and discussions that led to the HBP, but this description should suffice to show the strong embedding of new tools into large-scale research policy goals.[40] These are wide-ranging, and are intended to improve neuroscience on a number of levels, from budgetary concerns (more bang for their buck) to that of the workbench (databases for checking existing data). Note that

FIGURE 1
Integration of the 'Levels' of Neuroscience



Source: Reproduced from Pechura & Martin, *Mapping the Brain and its Functions* (1991), op. cit. note 2, 49.

these goals are built on an implicit assumption that science progresses as more and more pieces of the puzzle are put together: 'the hope – that having all data in one place will shake loose new insights about how the brain works'.[41] (Such statements also beg questions of location of and access to this 'place'.)

New Atlases

In this context, neuroinformatics broadened the scope of atlases and inscribed these tools in wider research and management agendas. The atlases, which in the 1980s served the relatively modest purpose of relating data from two technologies (PET for imaging 'function' and MRI for imaging 'anatomy'), became ambitious frameworks for integrating the various fields of neuroscience and for solving the crisis defined in the reports for the Decade of the Brain. The documents setting out the HBP formulate interdisciplinarity and overload as information problems: once knowledge is translated into a common, digital language, the subdisciplines of neuroscience will have generated their neuroinformatics solution. Interdisciplinarity and integration become a question of translation – a common strategy of modern techno-science.[42] The HBP acknowledges that such translation will require neuroscientists to cooperate in the creation of standard data formats and common languages for the various areas of the neurosciences, and that will represent a major challenge.[43] But

> ... ordering of data across multiple disciplines is not simply a question of finding a commonly accepted set of spatial and temporal units and naming conventions – though this is the way that it is often portrayed in the literature.[44]

A description from a textbook on brain mapping hints at the way these changes are implemented in the development of new atlases:

> ... databases will develop in which N-dimensional attribute lists will exist for each voxel in the human brain.[45]

Voxels, a neologism derived from the slightly older pixel (**pic**ture **el**ement), are then to be found in the brain? In a neuroinformatics context, yes... These atlases, it is predicted, will contain any number of types of data (n-dimensions) and these will be integrated in a digital tool (as voxels). Any kind of information, be it physiological or anatomical, can therefore be attributed to a particular voxel in the brain, all data being translatable into a similar format. This approach constitutes an important shift in neuroscience, where types of data (be they measurements of electrical activity, of cell-types, of sizes of structures, of chemical activity) about the brain have been the province of particular sub-disciplines, and gathered in particular formats (drawings, quantitative measurements, individual maps, scans). Yet, in these new techniques, these various types of knowledge are being juxtaposed and integrated into large digital tools.

If the problem is one of information, this suggests that information technology can provide a 'fix'. Yet, it seems that information technology is instead quick to play tricks on those expectations of universal translation. Consider the following transformations that accompany the digitalization of atlases. From serving as reference tools, atlases carry a number of functions. These are meant to

> ... provide a structural framework in which individual brain maps can be integrated.[46]

Data from individuals will also be related to the information contained in atlases; ideally, not only types of data will be bridged, but also different levels, from the more abstract generalization to the individual case. The atlases built in the course of the project therefore take on new shapes.

Indeed, I have been describing these resources as 'atlases'. But labels do not come easily. Neuroscientists themselves, in turn, celebrate or struggle against the collapse of terms that define traditional categories of reference works. Here are just two examples:

> Modern digital maps, however, have become databases [since they can be queried].

> ... all data such [*sic*] transformed constitute a human brain database... [and] such a database is already under development, based on a recently developed and continuously updating brain atlas.[47]

Traditional distinctions between atlas, model and database collapse. This collapse is related to the structures of these resources, which become more fluid because their digital format allows different types of data to be abstracted easily from gathered scans. But even though digitality explodes representational possibilities, not all and any are equally acceptable, as will be demonstrated below – these shifts are the result of technical possibilities coupled to evolving conventions, not of the original essence of the technology.

While it is difficult to know what to call these new tools, since they blur the boundaries between traditional types of reference works, they function nevertheless as authoritative repositories of information. As such, they continue to play one of the traditional rôles of atlases. Atlases, be they geographical or medical, have been used as educational aids and as reference works providing objective knowledge.[48]

If objectivity has characterized these types of resources, the concept may be a useful handle to compare the traditional form and function of these, and the possible changes brought about by the new neuroinformatics versions of atlases. As they take on a new digital form and are built to contain many types of information, they also become differently authoritative. In the course of developing a technologically supported basis for integrating knowledge, 'objectivity' is translated into a new context and undergoes significant transformations.

The Average Brain: ICBM 305

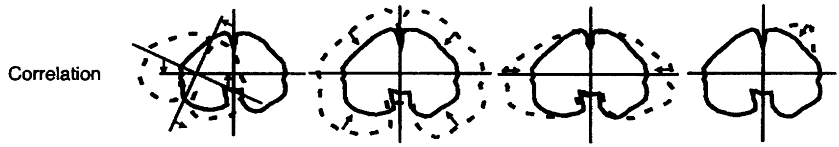
In the 1980s, the Talairach atlas, a paper atlas originally developed for neurosurgery, came into common use in the brain-imaging community. As noted above, it served to provide an anatomical reference for the functional data visible on PET scans, so that 'maps' of activations in the brain could be derived. There were several attempts to improve various aspects of the atlas, so that it would provide a better anatomical basis for analysing PET scans. One of the groups involved in this effort was the Brain Imaging Centre (Evans group) at the Montreal Neurological Institute (MNI). As a leading centre for neurosurgery and neuropsychology, issues of localization in the brain were important for both their research and their clinical purposes. A better reference tool would enable PET activation results to better be targeted to the anatomy of a given patient, or of groups of subjects taking part in an experiment. In the late 1980s, a digital brain atlas, built to represent the 'average brain', was developed by Evans and his colleagues.[49] While these improvements were meant to answer the needs articulated by researchers, and by clinicians to a certain extent, the approaches developed were also closely tied to the growing availability of scanning and computer technologies. Rather than being based on drawings or photographs of post-mortem brains, MRI scans of living brains could be used to create this average brain atlas.[50]

In the early 1990s, the MNI joined two other groups which, in the course of the preceding decade, had also been involved in efforts to improve localization tools for brain mapping. UCLA, the MNI, and the University of Texas Health Science Centre at San Antonio (UTHSCSA) formed the International Consortium for Brain Mapping (ICBM), so as to place a bid for funds in the Human Brain Project. Together, in 1993, they received a grant in the first round of the HBP.[51] These groups shared the view that standardizing and automating, at least partly, some aspects of PET data analysis was desirable, and all three had put forth suggestions in publications.

In forming the Consortium, the scope of the average anatomical atlas grew even larger than the basis developed by Evans, and the MNI brain, based on MRI scans of 'normal subjects', was expanded from a few dozens (in 1989) to 305, with a goal of 450 (150 from each site) to be achieved by the end of 1998.[52] The intermediate version of the average brain, the '305 version', was composed of young right-handed normals, 239 males and 66 females, mean age 23.4.[53] In this atlas, the data were derived from a sample of normal brains, which are the brains of normal subjects. Once selected, demographic, historical, clinical and neuropsychological data, as well as DNA samples, were obtained for each subject.[54] These subjects were then scanned with MRI, and these scans were averaged in Talairach space (a Cartesian space where every location is known through an x, y, z address). This average brain effectively constituted a new target brain (to which other brains could be transformed), and therefore served as a reference for identifying locations of activations when performing PET studies.

In building this atlas, an improved representation of the brain depended on the use of a better sample. The target brain of the original Talairach atlas, to which all other brains were to be related, was felt to be

FIGURE 2
Various Aspects of One Method for Transforming Brains to a Target Brain in a Standard Space



These are the ICBM atlas transformations, which make the brain scan data conform to a standard space. These transformations remove differences between brains that are considered incidental to the scanning session (angle of the head while lying in the scanner), or uninteresting (size, shape), and bring brains into a common space where they can be compared.
Source: Reproduced from Mazziotta et al., op. cit. note 50, 289.

too idiosyncratic since, as the criticism goes, it represents 'a single hemisphere of a single brain belonging to a 60-year-old French woman'. The Talairach atlas was said to lack representativity because the subjects of PET/functional imaging studies were usually normal young adults.[55] A better, more objective atlas was to be a more representative one, using more representative brains.

The normality of these subjects is based on what could be called a 'negative' definition of normality – that is to say, subjects are normal if they are untraumatized, unmedicated, unaddicted, non-diabetic, not pregnant, and not having had neurosurgery, psychiatric or neurological disorders. This kind of sample is sometimes called 'supernormal', because it eliminates so many of the features found in a 'normal' population. These criteria mean that a highly selective mechanism is at work here. Selection is not ordered by the explicitly disciplined randomization that dominates attempts by the social sciences to achieve ideals of representativity.[56] On the one hand, the claim to normality is instead based on exclusion. Normals are the mirror images of (clinical) populations that might putatively be studied with the atlas. On the other hand, these criteria also embed a number of neuroscientific concepts into the atlas, so that selection criteria themselves could be analysed as representing concepts that have evolved in the past centuries, and have at times been heavily contested (the relevance of handedness, for example).[57]

These features seem rather ordinary, and perhaps hardly worth mentioning, until one tries to think, first of all, of what is not encoded (being insured, or not, for health care; high or low economic status; living in urban or rural environments; and so on), and second, of just why these categories are banal. They seem so ordinary because of their pervasiveness across so many systems of classification. Here, however, these classifications become even more meaningful as the brain sciences are playing an increasingly important rôle in defining notions of self: databases become the sites of convergence of features of the brain;[58] kinds of brains match kinds of people along the lines of these converging categories, with potentially normative consequences. (I expand on this theme in the Conclusions.)

Automation and Standardization in the Average Brain

In order to use more than one brain to produce an atlas, a way of averaging the various scans had to be developed. Improvement of the atlas by using an average of many brains rather than a single specimen relied on the possibility of developing better algorithms for comparing brains, for bringing them together in a similar space. Incidental differences in brain size, shape, and position in the scanner needed to be overcome, to leave only what researchers considered the real anatomical differences to be averaged (see Figure 2). The use of multiple individuals was not new: Korbinian Brodmann used several specimens to make his famous map of areas in the brain, as did many of the scientists studied by Susan Leigh Star.[59] Even the possibility of comparing across individuals was not entirely new to neuroscience research. But certainly, averaging on this scale, and automating this process, are ideals that are associated with digital technologies.

Both elements meant to improve these atlases (the use of a larger sample and the development of better algorithms) were incorporated into atlas-making through the use of digital tools at nearly every step of the process. Digitized 'interfaces' were built to handle subject data in an automated and standardized way, which helped streamline the information gathering about subjects to be included in the atlas. In terms of imaging data, while the 'slices' in the Talairach atlas varied in thickness, scans were made with a greater regularity, according to standardized protocols. Once placed in a Cartesian space, the anatomy of the brain could be manipulated in terms of voxels, as a set of numerical values placed in a matrix, opening the door to a wide range of mathematical and statistical processes. Scans could be handled automatically by computers as digital files, and because of this possibility of using computers, algorithms to transform brains of different shapes and sizes could also be multiplied beyond what was possible for 'manual' operations by an embodied user relying on pencil-and-ruler transformations.

Not only the degree of standardization and automation is important here, but also the way digital tools were implemented. ICBM decided to develop an automated way to average scans across a group representing a population, a move that is telling of this group's alignment to the larger goals of the HBP described above. In contrast, a comparable atlas, also meant to improve the reference 'target brain', has used a very homogeneous sample (super-normal, right-handed Scandinavian males). Rather than averaging scans on a pixel-by-pixel basis, this group has chosen a set of anatomical landmarks to match brains to each other.[60] An operator had to identify these anatomical landmarks manually and visually, so that comparisons between brains in this atlas are based on homology of structures (the matching of significant anatomical areas), rather than on quantitative averages of voxels (which are meaningless, other than representing a quantity, a light or dark spot in a scan). For groups participating in the HBP, fully automated and standardized manipulations of scans, and the consequent freedom from the requirement for embodied expertise, were priorities.[61]

The criteria for selecting an adequate sample for this new atlas are also linked to the HBP. The Report leading up to the Human Brain Project had recommended gathering baseline information about subjects in a standard way: age, handedness, sex, education level, or any characteristic features of the subject of group.[62] The procedures for dealing with subjects further integrated the goals of standardization and uniformity of the HBP into the atlas of the Consortium; a program called NeuroCog was developed as an 'automated subject interview interface'.[63] All subjects were therefore 'entered' into the database in a standardized and automated way, in the hope of reducing human error and making the process uniform.

Finally, the list of attributes with which each component of the sample is marked takes on a particular significance in relation to the digital format of the atlas. In this respect, these atlases are more open-ended and less rigid than paper atlases, since sub-populations can be extracted, based on age,[64] gender, race, behavioural abilities, handedness, or other features for which the data have been marked.[65] That is to say that, in principle, the atlas could be queried to produce an average older female brain, or an average uneducated left-handed brain. Each feature for which the sample is marked can therefore be related to the data contained in the atlas, depending on the perceived relevance of these features to current research agendas. These features are made into differences that (could) make a difference in understanding the brain.

The flexible, multi-levelled structure of these atlases therefore relies on the possibility of comparing brain scans automatically, and of building an atlas based on scans transformed to a standardized space, and marked in standardized ways for certain features of a population. These transformations are possible because of the investments made in developing and automating new digital technologies.

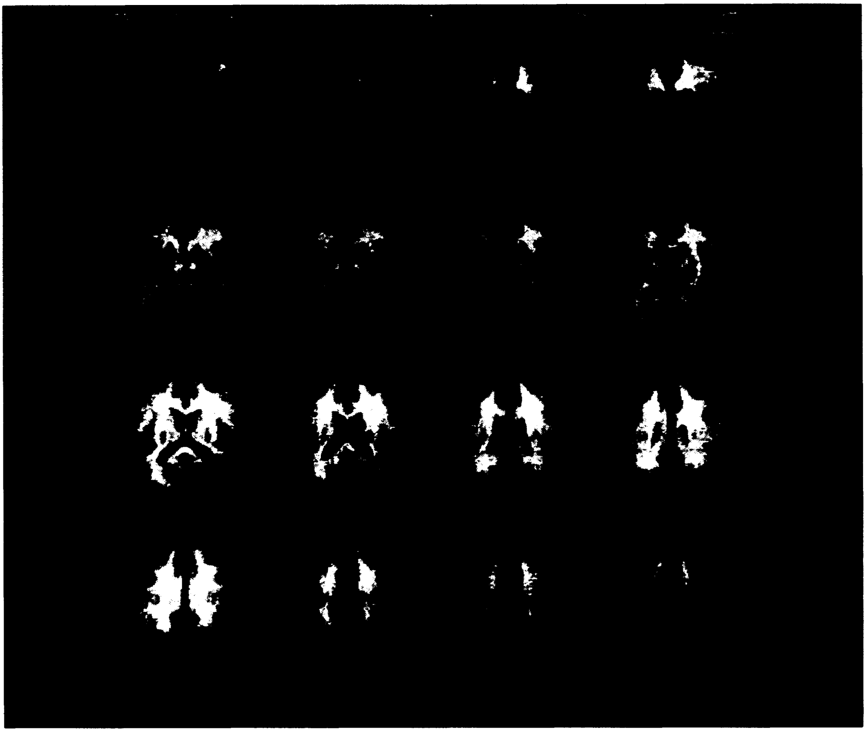
A New Object in the Average Brain Atlas

Besides the possibility of creating a new average brain to serve as a framework for integrating PET and MRI data, the expanded MNI atlas resulted in new ways of seeing the brain – in terms of its variability. The Committee's task force had raised the development of a new atlas showing variability; while variability between individuals was known to exist, it was generally acknowledged to be 'unknown', in the sense of 'not measured precisely'.[66] A call to action regarding this issue was published in the early 1990s, and interest in variability seems to have grown in importance since the 1970s with the development of the use of CT scanning and post-mortem co-relations of hemispheric functional differentiation. I suspect that this interest was always greater in surgical contexts, but was dealt with as a matter of expertise and clinical judgement, rather than as an issue requiring quantification. There seems to have been some resurgence of interest in anatomical differences between individuals as more attention was also paid to anatomical differentiation in the brain in general. For example, in the 1970s, when functional asymmetries were investigated, there were speculations that these would also be significant when observed between individuals:

> Since there are great individual differences in the extent of asymmetries, it will be important to investigate whether these correlate with individual differences in functions.[67]

The extent of variability becomes highly visible in the averaged brain. Once brains are transformed into a standard space, 'true' variability in the structure of the organ itself is preserved, while anatomical differences considered irrelevant are eliminated (as mentioned above, differences that

FIGURE 3
The Brain of a Normal Population



Source: Figure from Alan Evans, Louis Collins and Colin Holmes, 'Computational Approaches to Quantifying Human Neuroanatomical Variability', in Toga & Mazziotta (eds), op. cit. note 45, Chapter 13, 343–61, at 344. Reproduced courtesy of the Brain Imaging Centre (BIC), Montreal Neurological Institute.

'don't matter', such as size, are factored out by making the digitized scans conform to the same space). The average brain therefore focuses attention on the cortex as the seat of (significant) variability between brains. When the voxels in the scans are averaged, areas of greater variability are blurred, while in areas of lesser variability, the image is sharper than it would be in an individual scan (see Figure 3).

The average brain is therefore the simultaneous creation of a better reference space representative of a population, and a visualization of variability. As a reference tool it is considered more reliable because of its greater representativity, based on an average, a norm:

> Landmarks are derived from inter-subject stability of structures, rather than by simple assignment based on the anatomical features of a single brain.[68]

While the digital context of these atlases is novel, the notion that averaged images produce better landmarks is curiously close to early efforts to harness the potential for mechanical objectivity of the camera. Statistical thinking has traditionally insisted that features of interest that are truly important can be generalized across cases, and therefore identified. Compare the rationale of the average brain above, to Galton's description of the principle of his 'pictorial statistics':

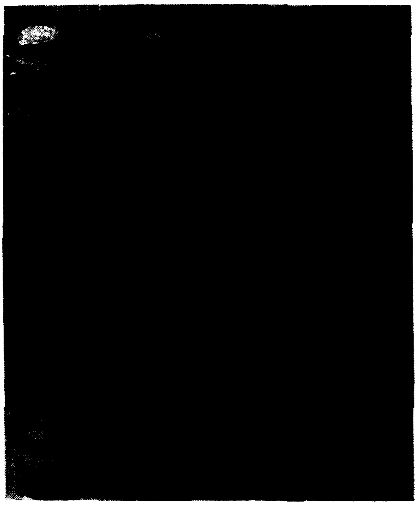
> Composite pictures are... much more than averages; they are rather the equivalents of those large statistical tables whose totals, divided by the number of cases and entered on the bottom line, are the averages. They are real generalizations, because they include the whole of the material under consideration. The blur of their outlines, which is never great in truly generic composites, except in unimportant details, measures the tendency of individuals to deviate from the central type.[69]

Note how the process of pictorial statistics making removes the idiosyncratic, an argument also made in the averaging of brain activation scans, in favour of the common stable features (see Figure 4). If atlases had traditionally shown the characteristic and the individual, in the sense of Daston and Galison, knowing the brain across subjects is now a newly prominent feature of brain atlases. I will later show how the two data-structures overlap in some respects and differ in others, in the production of their respective pictorial and digital qualities.

Since the mid-1990s, brain-mapping researchers have adopted the MNI average brain as a template on which to locate activations. It also serves as the template in 'SPM96', a data analysis package, making it the reference brain of a majority of functional imaging studies.[70]

What had begun as a better tool for localization of PET activity (a better target brain based on a larger, normal sample) became an exploration of the normal brain, and of its variability, and the standard baseline

FIGURE 4
Galton's Pictorial Statistics: Composite Photograph of the Military Officer



Source: Reproduced from Mark Seltzer, *Bodies and Machines* (New York & London: Routledge, 1992), 17.

reference with which to report findings. The requirements for a more authoritative, objective brain (through use of a large sample) coupled to the favoured technique of objectivity (standardization and automation) are productive of new objects, new standards and baselines adaptable in new ways. A number of digital tools interact to produce and organize knowledge. The average brain therefore came to provide a more authoritative reference from which to know the brain, by digitizing, standardizing and automating comparisons between brains. Through these comparisons, variability, as a new element of brain anatomy, literally came into view. The possibility of querying the atlas and extracting sub-populations was also established through the automated collection of standard information about subjects.

One Earth, Many Brains: Shifting from Average to Probabilistic Atlases

The creation of an average brain, which shows variability, was not the end point for the Consortium. ICBM researchers paid increasing attention to variability as an object of study in its own right. ICBM thus formulated a new critique of average atlases, and thereby a rationale for developing a new atlas. The merging of maps was acknowledged as important, but limited to a qualitative rendering of variability.[71] Around 1995, a new metaphor was appearing in print to explain the complexity and necessity of understanding variability in a probabilistic way. Members of the Consortium compared the problem of cerebral cartography with that of terrestrial cartography: there is only one earth, one physical reality, but many brains, so that the cerebral reality needs to be based on a large sample and account for variability within that sample. But if the average brain atlas could show some aspects of variability, variability could best be reported probabilistically.[72] That is to say that a quantitative evaluation of variability was deemed more desirable than its visual rendition in the average brain. The ICBM therefore developed another type of atlas, as researchers addressed variability in increasingly complex ways. They aimed to quantify it, and improve on what was perceived as too qualitative a demonstration of variability. This move to 'recover' variability as measurable, and not simply to 'picture' it, was born out of the tensions between a pictorial rendition of variability and a measurable quantifiable one, and led to further novel applications for atlases and digital tools.

Average Brains and Probable Labels: New Relations between Data

In the course of developing the average atlas, researchers had become very proficient in the manipulation of 'pixels' and 'voxels' in brain scans. In the average brain, these were 'registered', disciplined into a standard space, and their value automatically calculated. That is to say that their value, corresponding to a degree of darkness or brightness on a grey scale, was averaged. Further work at the MNI enabled the group to label voxels in scans for other types of features – namely, to label the type of tissue represented, or an anatomical region. In one project, a trained operator (usually a neuroanatomist) 'painted' the scans of one hundred brains with a pixel-wide 'paintbrush', identifying and labelling (segmenting) each area.

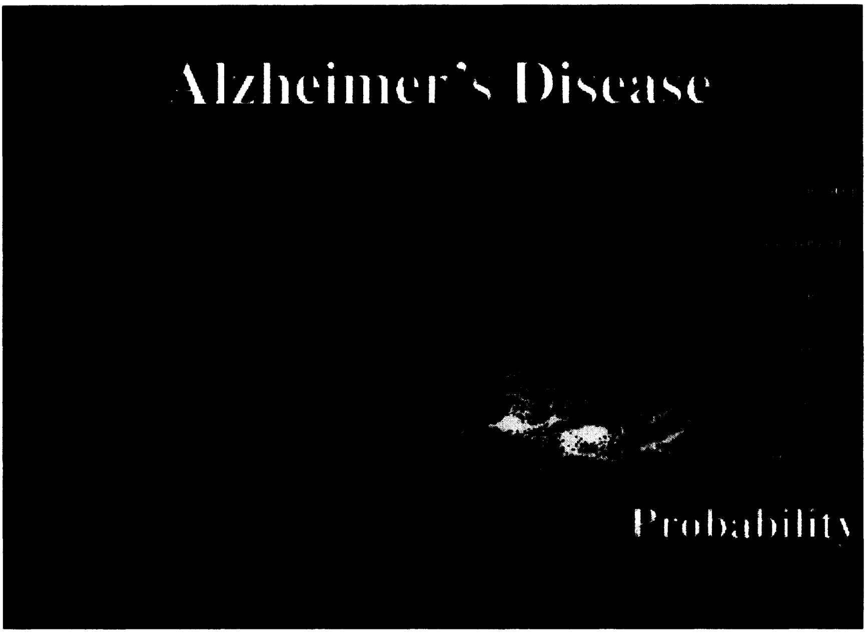
Another layer of information was therefore constructed around the scans. Not only could voxels be averaged with other voxels, but the relation of a labelled voxel to other labelled voxels could also be measured. This relation was rendered not only quantitatively, but also as a probability:

> . . . a probability map is then constructed for each segmented structure, by determining the proportion of subjects assigned a given anatomic label at each voxel position in the stereotaxic [reference] space.[73]

This kind of atlas indicates that, based on the sample of brain scans processed, at location x, y, z, there is a 56% probability of finding structure A, a 13% probability of finding structure B, a 6% probability of finding structure C, and so on. This means that locations in a brain scan, placed in a reference space, could be known as having a probability of belonging to a certain anatomical structure. When reporting activations from functional imaging studies, the anatomical area corresponding to the functional area could therefore be described with degrees of certainty. While human interventions (usually those of a neuroanatomist), and their dreaded inconsistencies, were involved in some of the labelling for these atlases, the need to standardize labelling between observers, and ideally to remove the observer, were clear concerns of the Consortium, as will be described below.

This work also extended the technologically mediated understanding of variability of the brain, and reshaped a number of neuroanatomical concepts. The structure of data in these atlases, and the manipulations of digital technologies, give rise to new concepts and new ways of knowing the brain. Anatomy, in the paper atlases, was the correspondence of a label to a structure, a relation of identity. Structures are here defined according to their 'occurrence' in a data set. Like the average brain, this too is a new representation, clearly different from traditional understandings of neuroanatomy. Whereas in the classic anatomic atlases, the goal is to identify the structure to which a location in the brain of a given individual brain belongs as unequivocally as possible, here, locations in the brain are defined in terms of a representation that stands for a population. This understanding is not only relative, but also quantified. Rather than visualizing variability, as a more or less blurry area on a representation of averaged scans, this approach provides a quantitative understanding of variability for a population. When recast in terms of a population, across large numbers of scans and in probabilistic terms, relationships between label and structure are relative to a sample, and the identity of a structure becomes a question of probability. This dynamic can also be extended; a voxel can be known for the probability of belonging to a structure, for the probability that it is abnormal, or that sets of voxels represent changes in volumes or structures in the brain.

FIGURE 5
A Probabilistic Brain Atlas



The data from subjects are pooled, and will enable the evaluation of the probability of a point being located in a particular region, or of being 'normally' located. Such an atlas might be population-based (that is, of schizophrenic brains, etcetera).
Source: Reproduced from <*http://www.loni.ucla.edu/~thompson/disease_atlases.html*>, courtesy of Paul Thompson, UCLA Department of Neurology.

In this atlas too, the flexibility of digital tools is manifest. Objectivity can be constantly transformed. As each scan is added to the set, the probabilities of the atlas change, so that the statistics improve as more data are incorporated.[74] Quality therefore improves with quantity in this framework. Canguilhem's aphorism, 'the norm points to the rule and extends it', pronounced some 50 years ago,[75] seems extraordinarily appropriate to the conceptual underpinnings of the Probabilistic Atlas (see Figure 5). This particular point highlights how these tools must also be considered in terms of their involvements with the way they structure the work of researchers. We have seen how the atlas serves to displace the inconsistent observer, in favour of the more highly valued automation. Yet not all the features of the atlas are desirable. Because atlases are used as baselines for brain-mapping studies, a researcher trying to write a paper doesn't want the localizations about which she is trying to write a coherent story to be a moving target – which is what they literally would be if the probabilities of locations in the atlas were changing with every additional brain scan entered. In practice, scans are not added one by one but rather periodically, so that the atlas, via the interface to users, is 'quarantined', and even periodical changes have to be negotiated with users by the atlas-makers. A copy of the earlier version of the atlas may be kept as a way of accommodating researchers who may still be working on an analysis using that particular version. This is a clear example of how work practices are shaped by these technologies. The negotiations also highlight another aspect of the tensions identified by Bowker, between article and database as sites of knowledge-making – these two ways of structuring knowledge sometimes have incompatible time-cycles.[76]

Pathological Probabilistic Atlases

If variability between brain structures was quantified in atlases of the normal brain, a similar recasting of notions of pathology also occurred in the probabilistic atlases of disease. Between the early and mid-1990s, as the Consortium work progressed, the MNI developed expertise in the analysis of large numbers of scans, linking various kinds of software into 'analysis pipelines'. These are sets of data-processing tools and analytic procedures in which raw data (scans) are automatically processed. These pipelines were adapted to deal with abnormal brains, thereby linking clinical data (scans of patients) with the lab's analytic procedures. Using these techniques, the MNI has embarked on a commercial venture in partnership with a company that produces scanners, and has formed a company that runs the imaging analysis component of clinical drug trials.[77] Through one such contract, the centre compiled 1850 scans of 460 people with multiple sclerosis (MS), which have been entered into the MNI reference space and processed through analysis pipelines.[78]

In being processed through this particular pipeline, voxels are labelled for the type of tissue they represent. For example, in the MNI's trial of drugs for treating multiple sclerosis, brain tissue was labelled according to grey matter, white matter, cerebro-spinal fluid (CSF) or lesioned tissue, instead of being 'painted' according to anatomical labels.[79] This means that the volume occupied by different types of tissue can be automatically calculated across large samples, and in scans taken at different times. Based on the measurement of statistically significant increases or decreases in volumes, these tools have been applied to clinical trials. Pipelines therefore produce quantitative data about the potential decrease of a 'lesion' load, in relation to the administration of a placebo or drug. Differences between scans that would not be evident to the naked eye of the observer become apprehensible through a quantitative analysis. As imaging studies become part of the required evidence in drugs trials, quantification in turn forms the vehicle for a more efficient circulation of knowledge claims.[80]

Insofar as all scans must conform to pre-determined parameters in order for the software to operate, this dependence on standardized procedures is a condition for the use of data in these new atlases. Further standardization, beyond the imaging research laboratory, was involved in pursuing these evaluations of clinical brain scans. In this case, scans were not gathered from subjects coming to the lab, but from patients in a number of geographically dispersed clinical settings. In order for 'pipelines' to handle hundreds of scans automatically and analyse them quantitatively, each site must participate in the coordination of scanning. The coordination of work done at these sites required the involvement of a clinical trial manager. He told stories about 'being able to rely on some centres', or knowing which people he could call on when in a crunch and pressed by time. These accounts of how he 'got the job done' in turn relied on developing trust, and the need to visit sites to get to know people – the need for a certain embodied kind of work. Maintaining the system that led to the production of the atlas seems to have required human judgement – judgement perhaps not so different from that of the anatomical illustrator, though displaced to a different point in the production of representations.

Even though imaging would seem a highly technical process, with parameters that can be specified and standardized, and delegated to machines, human relations and interventions were needed to compensate for local variations and to make the data suitable for the pipelines. To rephrase a well-known formula in the light of this case, 'mobiles', especially digital ones, are perhaps not so much 'immutable',[81] as recreated according to conventions, and allowed to circulate in the locales where these conventions are operating. To expand the power of these automated, quantified analyses to address clinical conditions, further standardization and coordination of work in new locations are required, and clearly, face-to-face interactions have not entirely been evacuated from this context of work.

A New Object in the Probabilistic Atlas: The Essence of Disease

As in the case of the average brain, which showed variability, the gathering of digital data about MS lesions in the brain also led to the representation of a new scientific object of study. While the company sponsoring the trial was interested in the effects of the drug under trial ('the numbers'), the imaging data remained at the disposal of the MNI. For its own research purposes, the MNI has used the data from these clinical trials to generate the MS brain, a 3D representation that indicates the likelihood of the location of lesions in MS. As a result of new modes of data handling, aggregated scans come to show not the brain of a patient suffering from MS, but rather the image of MS itself. Across scans, across patients, across the clinical manifestations of symptoms, the atlas

> . . . shows the most likely locations for MS lesions within a population and is a convenient way to distil a large amount of population data into a single entity.[82]

This representation of disease is more a synthesis than it is an average. It is the image of disease across cases, in contrast to, say, how the disease might be most likely to appear in a typical case.

This view of disease as concentrated in a single representation has also been used to describe other atlases. One such atlas was built using scans of the brains of schizophrenic patients and normal subjects. This atlas is 'a concise numeric and visual summary of the group as a whole', and the statistically analysed difference between the two is an 'image [that] presents a descriptive picture of the size of group differences'.[83] The essence of disease can be visualized in a scan, as can the essential differences between normal and schizophrenic brains. Again, these new notions of disease are possible when the relevant brain differences can be identified, that is to say, once a standardized digital framework for comparison has been developed.

The atlas shows a refined synthesis, but it is quite different from the 'ideal', as defined by Lorraine Daston and Peter Galison. This version of the ideal, rather than being based on the observers' mental distillation and expert judgements, is the result of a pipeline analysis and a framework for comparing and labelling brain scans. Individual cases are to be distilled, not by judgement of the experienced eye and mind, but by the application of the many automated and mathematically validated tools described above. In early modern medicine, knowledge of the essence of a disease, above and beyond the idiosyncratic manifestation of a disease that could be observed in a patient, was considered part of the physician's abilities. In these atlases, the essence of disease arises from the automated, large-scale comparisons of standardized scans.

Furthermore, in terms of traditional anatomical atlases, this atlas points to an important shift from the tendency to show the 'characteristic' representation of a diseased organ, a convention that is especially long-standing in anatomy.[84] Here, however, pathology is constituted as the distribution of lesions as identified through automatic processing across cases, not as observable individual instances.

Further applications for the probabilistic atlas were also being developed during one of my visits to a lab, and give insight into the importance of avoiding observer intervention in the construction of the automated processing of brain scans. Analysis software to identify some of the sulci ('valleys' in the cortex) from MRI scans was being developed and validated. The software currently identifies the probability that a fold corresponds to a given structure, the central sulcus for example, and the goal is ideally to be able to identify the desired structure on a given subject's scan. As in the other atlases, the algorithms are validated manually, a tedious and time-consuming job, requiring not only neuroanatomical training, but (somewhat paradoxically) also the ability to learn to see with the display programs which handle these images.

But, while tedious, this work is done with the understanding that manual (or visual!) validation will confirm the results of the automated tool, and thus liberate future users from the need to 'paint' the structures manually, and ensure the mechanical objectivity of the process. While human intervention may sometimes be needed in practice, the ideals pursued are those of automation and standardization; students and researchers working on these tools usually reported avoiding human inconsistency, or removing the noise of human error as a self-evident motivation for the work. This perceived need to avoid human fallibility was also visible in the instructions and support work provided by the local computer experts to researchers: programming was done with the goal of avoiding 'interaction', and of automating data processing as much as possible.[85] The use of these automated tools therefore relies on the normalization of the process of analysis (assumed after validation), and the 'normality' of scanning procedures and of the brains under scrutiny.

The ideals to which these tools strive consist in removing the individual, both as idiosyncratically ill (MS is defined across a population) and as subjectively (inconsistently) interpreting or manipulating data. This approach produces frameworks and models of the brain based on purified data, which have undergone disciplined transformations so as to yield an idealized object. What is also new, therefore, is the type of empirical instances that are favoured.

> If certain kinds of entities and certain kinds of context are being excluded from entering into the databases we are creating, and those entities and contexts share the feature that they are singular in space and time, then we are producing a set of models of the world which – despite its frequent historicity – is constraining us generally to converge on descriptions of the world in terms of repeatable entities: not because the world is so, but because this is the nature of our data structures.[86]

These atlases thus correspond to privileging, in Daston and Galison's terms, the ideal or the average, at the expense of the typical or characteristic.

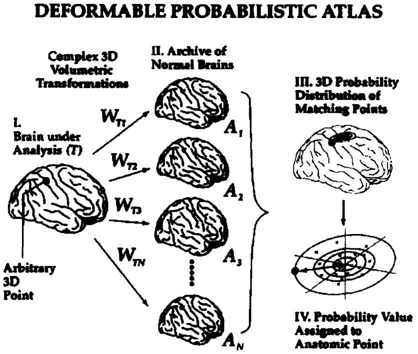
Variability (Diagnostic) Atlases

The development of these atlases is clearly one of gradual shifts in the manipulations of scanning data, rather than one of radical breaks between old and new endeavours. Building on the average and labelled probabilistic approach, another type of atlas has been developed by the Consortium. The norms that are established by the representations discussed up to now are built around two concepts: that of the average as a reference for a group; and the possibility of illustrating or determining statistical probabilities for features of a group. But the projects of the Consortium are more ambitious than simply providing a better reference tool for the field and, as mentioned above, focus on building a normative model of the human brain with clinical applications.[87] Based on the probabilistic labelling of anatomy in the ICBM project, one of the goals for probabilistic atlases in the HBP is to develop their use as a diagnostic tool:

> Such capabilities [of giving probabilities for features] allow for a rigorous analysis of normal variability, as well as variability in structure and/or function as it relates to disease, such as those thought to be associated with mental disorders and other brain pathology.[88]

To understand the logic of this atlas (Figure 6), it is useful to think again of the single voxel being manipulated. In this atlas, the measurements made

FIGURE 6
The Structure of a Probability Atlas



Source: Reproduced from <*http://www.loni.ucla.edu/~thompson/MedIA_pics.html*>, courtesy of Paul Thompson, UCLA Department of Neurology.

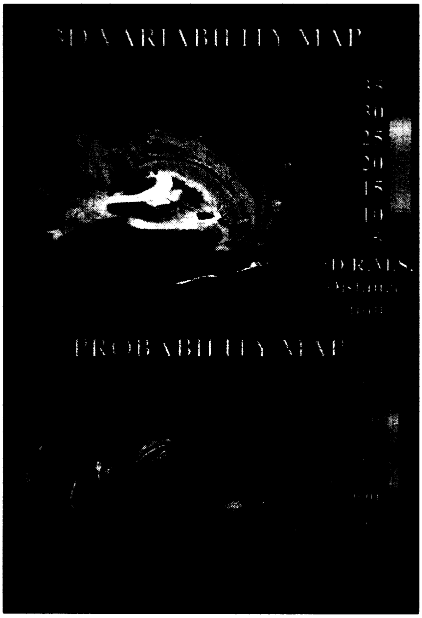
around this voxel concern its relation in space to other voxels. Specifically, this means that the direction and distance a pixel has to be 'moved' to be aligned with a given position is measured. This provides a variability map, which shows by how much a given voxel can vary.

So whereas the average scans showed variation as an aggregate of anatomy of many brains, in this kind of atlas, variability is to be understood statistically, as a feature of the brain that can indicate normality or pathology in a single brain. In order to evaluate a particular case, the reference space must still take into account the normal range of variation: '. . . any comparison of individual against normative data must still account for anatomical variability among individuals, particularly in cortical folding'.[89] The differences between the subject's scans and those in the atlas must then be quantified and determined to fall inside or outside the normal range.

The proposed probabilistic atlases will relate a new subject's MRI to each and every brain in the archive by warping the new brain to the archived ones. The structures are then compared as to their distribution, and a probability is issued, to determine the likelihood that the new subject's data fall within the configuration of the archived brains. Two types of representations can be made from this atlas, either 'variability maps', based on a group or population, or 'probability maps', indicating the relationship of one individual to this group.

The particular manipulations of the voxel here, as in the preceding atlas, involves being brought into a standard space and labelled as belonging to a particular structure, or occupying a particular volume. A further layer of information is added in these atlases: for a given group, the distribution of voxels in space for a structure is further calculated (see Figure 7). This provides a variability map, in which the normal range of distribution for a brain structure is given as a coloured representation, with

FIGURE 7
Probability and Variability Maps



These images are hard to reproduce and best seen as a three-D representation on a colour monitor, but basically, you can see an image of a patient's brain (bottom) compared to a population in terms of variability of the brain (top). Where a voxel falls outside the normal probability for that part of the brain, it would appear in red – the traditional colour of alarm. The goal is to be able to associate patterns of abnormal variation in specific patients, with particular conditions (Alzheimer's, schizophrenia, and so on).
Source: Reproduced from <*http://www.loni.ucla.edu/~thompson/MedIA_pics.html*>, courtesy of Paul Thompson, UCLA Department of Neurology

'hotter' colours representing greater variability. In keeping with the concept of variability developed from the previous atlases, some areas like the cortex have a greater range (hot colours) than areas that are more stable across subjects (cool colours). Comparing a subject's scan to the probability map produces a second representation. The individual's scan is therefore colour-coded according to whether voxels fall within the normal range (cool colours) or else represent a deviation from this range, and probably represent a pathological variation (hot colours). A number of variations on this basic principle exist, so that volumes, changes in location, or the shape of particular structures, can be compared in this way, depending on the aspects of the brain that are deemed of interest clinically. In the logic of these atlases, each of those interests can be translated into a particular kind of manipulation and measurement of the brain as a set of voxels.

The significant step taken in the constitution and proposed use of this atlas is that the individual scan is only meaningful in terms of the probabilistic atlas. The individual scan becomes a valuable piece of information once it has been 'overlaid' with the significance that comparison to the norm imparts to it. Normality emerges from large-scale, quantitative comparisons, and analysis based on voxel-to-voxel comparisons can provide a picture of a disease, where no typical pattern was visible:

> In the future, precise models for the cortex that encode information on structural variability will provide a better understanding of the complex regional changes that occur as a result of developmental processes or under pathological conditions. Accurate quantitative measurements may then be used to obtain objective criteria for conditions such as global or regional cerebral atrophy and for the assessment of subtle gyral or sulcal anomalies that may be specific to certain disease states.[90]

This atlas can handle scans in their typical, clinical form (as images), since it is built using pattern recognition principles. This feature might significantly further the clinical application of the atlas, since the visual qualities of these digital scans are important elements in making them 'fit' the kind of evidence preferred in the clinical context.[91]

The ICBM plans to pursue a probabilistic approach to the brain for other levels of brain anatomy and function. The goals of the researchers for integrating other levels of data are parallel to those developed around anatomical data – a new paradigm for developing tools of brain exploration has emerged.

Based on ideals of large-scale automated data gathering and data analysis, these anatomical atlases, be they average, probabilistic or deformation-based, have provided new tools for manipulating and comparing brain scans. These are constitutive and representative of the particular ideals of objectivity of ICBM and the HBP. All the relations of voxels to structures, and to the normal range of variations, are thoroughly quantified, and objectivity further guaranteed by the use of statistical tools that test these relationships. These tools have also been the context for the production of new objects of scientific knowledge: the average 'normal' and 'sick' brain, the variable brain and the probabilistic brain. Finally, and directly in relation to the HBP, atlases have provided idealized brains as frameworks for integrating data across technologies and populations.

Totalizing Atlases

In terms of the larger goals of the HBP, the average brain has therefore become a reference space that can be used to integrate many other types of data. The UCLA component of the Consortium has gathered digital images of post-mortem tissue (which provide better resolution than MRI) that will be matched to the reference space. In principle, other types of data can be integrated as well, adding a functional level and elaborating functional landmarks. Plans for the next five years of funding involve establishing two more probabilistic levels. Cytoarchitectonic data (at the level of brain cells) will be gathered, and the variability of the brain's anatomy will be defined on the level of distribution of biochemicals (and receptors at cell level), which have a functional component. This will serve to link gross anatomy to the level of cellular function, as well as to data from PET and EEG studies of function.[92]

The Consortium describes the integration of these data as likely to lead to an understanding of the correlation of function and anatomy, one of the general goals of the Human Brain Project.

> We make no assumptions about the relationship between structure and functions in the human brain, at either a macro- or microscopic level, except to state the obvious, that these relationships are complex and poorly understood. Further, we are not proposing that we will unravel this complexity with the data collected in the context of the consortium program. The development of a probabilistic reference system and atlas for the human brain simply provides the framework in which to place these ever-accumulating data sets in a fashion that allows them to be related to one another and that begins to provide insights into the relationship between micro- and macroscopic structure and function.[93]

What began as a repository of anatomical data, a brain more representative because based on multiple subjects, has become a framework for integrating many levels of data and articulating relationships between them. How this cross-disciplinary integration will work will be an interesting question in this next stage of development of the atlas, as ICBM expands its atlases, and as the HBP's various grantees attempt to integrate the resources developed under its aegis. Bowker notes that it is never a simple case of 'nesting' (of various timelines into a biodiversity resource) and that this process always involves concessions on the part of one or the other system of classification, to the dominant one.[94] One can wonder whether the researchers do not protest too much about this lack of assumption regarding a key question in neuroscience. Frameworks are not neutral, and this one places brain mapping at its centre.

Conclusion

As we have seen in the discussion of specific atlases above, complex representational strategies can distil individual features to form average brains and make these into a highly-valued representation, warranted by the stabilities across the multiple instances they represent (average atlases). They can also embrace these differences and render them as exquisitely as possible for each individual (probability atlases). In light of these developments, earlier atlases are accused of being highly observer-dependent, of using purely qualitative measures, and of being based on 'pure visual inspection'. As such, researchers claim that they do not allow generalizations, due to the large variations in extent and topology between individual brains – as opposed to what the developers of atlases, such as the ICBM, claim the digital tools can do. But these current judgements are based on a new set of criteria that arise with the development of neuroinformatics, which foster large-scale sampling and automated processing – remote from the individual as embodied object or subject.

Quantification, standardization and automation are embedded in pipelines and computerized tools. These are all elements that shape and sustain the objectivity towards which these atlases strive. The removal of human interference and mathematization of observations in scientific practice has been noted before.[95] What is new in these atlases is the extent to which these ideals are taken, as pipelines guide the entire trajectory of data, from gathering, to analysis, to the representation of results. Large-scale sampling has become possible with scanners and informatics tools, so that typical or ideal representations are no longer considered suitable for these atlases. Furthermore, ever increasing quantity seems to hold the answer. Atlases therefore have 'an open data structure for any future enlargement of the sample size'.[96] The quality of the representation of the brain is relative to the sample gathered, improving proportionately to the sample size, while also being open to qualification in terms of features of a subset of the sampled population.

A New Digital Objectivity?

I will return to the interaction of these many processes later, but first, I wish to draw out the specificities of digital objectivity in these atlases. Two elements, not raised by Daston and Galison in their discussion of paper atlases, seem typical of these digital resources: the combination of types of techniques of objectivity in dealing with images; and the extension of objectivity to the use of the atlas. Their absence from the discussion of paper atlases is at least partly due to the fact that they grow in prominence when atlases are in a digital format.

First, the digital format of the data that are incorporated in these atlases contrasts with the optical use of images for creating atlases. When these atlases are compared to earlier projects based on images, the extent to which quantification and automation, as associated with the digital, play a rôle in this type of objectivity is further highlighted. The project of using the power of the photographic image pursued by Galton and his contemporaries overlaps in important ways with the goals of these atlases. For example, in the latter part of the 19th century, attempts were made to archive and use images (especially photographs) for scientific purposes.[97] Some of these efforts are quite similar to the goals of the digital atlases described above: to go from the idiosyncrasy of the individual representation to the elucidation of the 'type' through multiple comparisons, involving a merger of optics and statistics.[98]

The images produced by Galton are perhaps best known, but form only one of several projects of archival control of, and through, photography in the fields of medicine and law.[99] In order to deal with large amounts of data, Galton chose to collapse the archive into the photograph and capture the 'type', while Bertillon incorporated the photograph in the archive, to capture the individual.[100] This tension between the revelation of phenomena across instances, and the identification of a particular (deviant) instance from large amounts of data, is also found in the new brain atlases. In the multiple sclerosis and schizophrenia atlas, the disease and its progress are invisible in a single case, but can be apprehended across many scans. With variability maps, the focus is rather on identifying the individual, in relation to the archived data. Emphasis is placed on overcoming the individual variations, so that the essence of disease arises, or on seeking out that very individuality – in ways similar to the efforts based on photographs.

Yet the digital form of scans plays an important rôle which should not be underestimated, and which comes into view when this comparison is pursued to the level of the manipulation of the data. The digital form differentiates the new brain atlases from Galton's and Bertillon's efforts based on the optical form of the photograph, because the image itself is open to further quantification. If the classification of photographs was frustrated by the 'messy contingency' and the sheer quantity of available photographs,[101] in the case of scans, digitality holds the promise of tighter control of the very content of scans as data.[102] While the objectivity of the photograph relies on the mechanical objectivity provided by the camera in making the image, the objectivity of scans further involves their digital format; the contents of the image are considered thoroughly quantifiable. The cumulative objectivity of the brain atlas does not reside in imagistic effects, but in the bits of numerical data it contains.

A second contrast between paper and digital atlases concerns the use of atlases, once they have been created. With the paper atlas, the scientist wishing to use the atlas must infer from the representations it contains, and relate what is learned to the individual specimen encountered. While Daston and Galison do not describe this process explicitly, they seem to assume that it is mental, probably acquired as part of a learning process.[103] In the case of the new brain atlases, the objectivity built into these also concerns their use; ideally, individual data are to be automatically compared to the representations in the atlas, a process also supported by a statistical and quantitative logic. Consider this new definition of the success of an atlas:

> The success of any brain atlas depends on how well the anatomy of individual subjects match the representation of anatomy in the atlas.[104]

Here, the comparison between an atlas and a new case to be evaluated is based on matching, on the possibility of 'warping' one brain to another automatically, and of evaluating this match with a degree of certainty or a quantitative evaluation of 'fit'.

Whereas the traditional atlas is heuristic, and the observer (surgeon or anatomist) must make a judgement call in applying her knowledge, in the new digital atlases this process is automated. Rather than being based on an embodied judgement, the new atlases are used to produce automatically a degree of certainty as to the identity of a given voxel's location. This is further expressed explicitly as a quantitative probability, a degree of confidence about the way a reference work and the individual case are related. Not only is the variability in the performance of the human observer done away with, but these atlases also offer the possibility of quantifying the experimental error – a feature that is also stressed as an advantage of these new atlases.[105]

Part of the reason for this shift might be the reconfiguration in the digital context of the subject/object relation, which Daston and Galison posit as the defining axis for understanding objectivity. The automated evaluation built into these atlases, what I have termed 'database diagnosis',[106] might further indicate the extent to which the pole of the 'subject' has been diminished in this context.[107] The observer hardly appears at all in digitalized work based on a virtual object (such as the normal brain of these atlases), and when she does, it is then only to test the pipelines, not the accuracy of the transformations – for which there are other automated testing methods. In a sense, both changes (the extension of standardization and automation to the contents of the image and to the use of the atlas) are part of the same pursuit. The subjective elements of the earlier atlases, described in recent texts as purely qualitative, and purely visual, are also purely dismissible, in light of the HBP's antithetical purity of standards and automation.

Digital Objectivity and Cyberscience

Rather than linger on this further episode in the death of the observer, I would like to take this analysis one step further and ask what this mode of objectivity might mean for the practice of science. The rationale for Daston and Galison's exploration is the need to refine definitions of objectivity, so as to have a coherent debate about whether science is objective. Their contribution is therefore a historicization of the concept, and an illustration of its varying guises. They also point out that while various modes of objectivity may co-exist, one or the other tends to dominate during certain periods, as tools and ways of practising science change. One way of explaining this dominance can be described by what Geoffrey Bowker and Leigh Star, in their study of classification systems, have termed 'convergence'. Convergence is the process by which representations and the world come to resemble each other. Furthermore, Bowker and Star note that classification systems are often invisible, because they are 'naturalized' into routines of life. The same goes for atlases – by studying the progressive development of atlases, and the negotiations that occur as these tools encounter new disciplines where they are neither natural nor routine, this convergence is somewhat more visible because more tentative. Convergence makes for strong accounts of the world, however, when there is a rapprochement of standards, categories and technologies in large-scale information infrastructures.[108]

Let me expand on how convergence might operate when large-scale information structures are digitized and available through electronic media. First of all, the digital form and structure of these atlases provide an interface in which a variety of techniques of objectivity converge and reinforce each other. Along with the mechanical objectivity of scanning and imaging technologies, these atlases are constituted through the mobilization of computer-supported statistical and quantitative apparatus, which provide a further mechanism for validation and for guaranteeing objectivity. The powers of the undeviating and tireless machine are multiplied in these atlases, through being coupled to a statistical and quantitative armamentarium.[109]

As we saw in the earlier discussion of the average brain as the 'new' normal brain, the possibility of correlating scans is inseparable from the development of standardized parameters for making these comparisons. The gathering of large samples is made possible by the development of conventions, the standardization of formats, and by automated procedures based on digital technologies and techniques – these atlases have 'no print-on-paper' equivalent.[110] Scans gather added value by virtue of their being mobilized in a Latourian sense, while quantification, analysis and evaluation of data, accomplished automatically, are taken to guarantee their integrity as data. The reference tool becomes the site of discovery, as new knowledge emerges from compilations and comparisons, as scans become more easily available, and as methods for compiling and comparing them automatically are developed. It is now clear how the collapse of the traditional definitions of atlases with which researchers grapple comes about – maps, databases, atlases and scans are all made to translate, to move from one format to the next. This is also the source of their 'power': each level of information can be cascaded into the next.[111] There may be something particular about the kind of science pursued with these techniques and technologies that can be coupled in a digital resource, and about the way the various objects that make up the database merge and blur so as to appear seamless. I will make one last incursion into the case of ICBM's work to illustrate what I mean by this convergence, and to show how digital objectivity might be significant for the characterization of cyberscience.

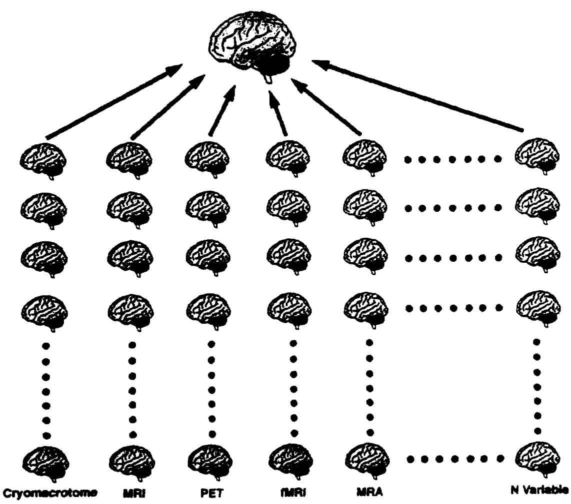
Neuroscience Saved?

The notion of convergence is also useful in elaborating how digital objectivity might be significant for the production of knowledge, not only at the level of objects of knowledge and techniques, but also in terms of how new projects of discovery might be formulated. At the beginning of this paper, I evoked two key issues from discussions in the Decade of the Brain: the brain as a set of voxels known in n-dimensions; and the crisis of information in neuroscience. Both issues are part of new modes of data acquisition and handling, as described in this paper, through a specific objective formulation and comparisons of 'the normal' in various forms. To return to the rhetoric of the Decade of the Brain: What will save neuroscience? The answer, in a single neologism, is 'neuroinformatics' – which, as we have seen, comes to stand for many new conventions, tools and practices in neuroscience. But it should also be clear, after discussing the new atlases, that, in being saved, neuroscience will also be born again.

In these new atlases, ideals of integration are given form, and the effects of new approaches and new digital tools on the kind of knowledge produced become clear. The resources described in this paper all have in common the use of large-scale sampling and analysis, and the redefinition of representations of the normal brain. These common features point to the intersection of two important themes in the constitution of atlases as digital resources. First, these tools are the materialization of the 'needs' of neuroscience to develop ways of pooling data. Second, they reinforce the notion that advancing knowledge about the brain, and distinguishing normal brains from pathological ones, are only possible when using large amounts of pooled data. In turn, the means selected and developed to achieve this pooling in the HBP resources have focused on the use of digital and electronic media.

By comparing Figure 1 and Figure 8, one gets a sense of the conceptual and technical work that has taken place in the course of the HBP. Figure 8 shows simple dotted lines between various types of data. Integration between disciplines is a matter of translating the various versions of the brain they produce. Living and dead brains are also to be correlated in this atlas; the effects of death erased by a proper algorithmic correction. These translations are possible when data are made into a feature of a voxel, this voxel constituting a reference space in which different types of data meet.

FIGURE 8
The Potential of the Integrating Atlas as Proposed by ICBM in 1997



Note the conceptual and technical work that separates this representation of 'integration' from the integration of levels proposed in 1992 (see Figure 1). The representation of knowledge has been streamlined; each subdiscipline is a version of the 'same' brain. The relation of these various levels has become defined as one of standardization of formats and of translatability.
Source: Mazziotta et al., op. cit. note 50, 291.

While they have been discussed here mainly as tools and authoritative references, the new atlases are also meant to fulfil a function as tools for research and discovery:

> Computerized brain atlases are not only for the identification of structures but are also becoming a research tool for parcelling the human brain functionally and structurally and for meta-analysis of brain function.[112]

The importance of notions like 'data-mining' have been emphasized in more recent reports on the HBP.[113] Along with the development of these virtual brains, the locus of neuroscience research can arguably be said to be changing, moving from wet labs to voxel space, from workbench to console and monitor. Similar moves in biology, especially in relation to the Human Genome Project, have been defined as a paradigm shift in biology.[114] While the efforts in neuroscience are pursued on a smaller scale and arose later than those of the Genome community, there are signs that the atlasing mode of work is having an impact on some research efforts. Perhaps most striking among these is the close, almost synthetic approach of atlasing practices, and of those for running clinical trials. Pharmaceutical companies are especially interested in the 'pipeline' analyses, such as those the MNI can provide, since the companies can easily perform 'audits' of the results provided: automated manipulations are easily recorded and verified. The manner in which authoritative, trustworthy results are produced in ICBM, and the standards to which pharmaceutical companies must answer, are very compatible.

But such close collaboration is not restricted to projects that might be expected to have a more 'bureaucratic' set-up. Bodies dedicated to the pursuit of scientific research, like the NIH, are also interested in the atlasing approach. Three elements from neuroinformatics are visibly shaping research, even in the early stages of a new project to study development (the 'children's brains' project). First, there is a desire to give added value to a set of clinical scans by considering them as a sample, and to enhance these data through further analysis. Second, this large-scale sampling shapes the questions being posed in this endeavour; elements of interest are only apprehensible through large-scale comparison. Third, in making these comparisons, (human) inter-rater variability proved to be too great and led the NIH to seek the MNI's expertise, and to a close collaboration with the MNI to pursue this research. The dynamics of standardization and automation for pooling data, the idea that aggregation of scans will yield insights, and the search for bypassing human judgement in the evaluation of large numbers of scans are aligned to what can be accomplished with digital objectivity as a 'complex of technologies'.[115]

As an approach to pursuing neuroscience, neuroinformatics thus seems to be shaping new research, above and beyond what individual technologies might be able to accomplish. During an interview, a leading researcher, when asked about the work of the Consortium, expressed the following view:

> Oh, this is exciting. That is a really unique way to look at very subtle differences between individuals and brain anatomy. You wouldn't be able to do that with the naked eye, and you wouldn't be able to do it with ten subjects. You need a large database, you need sophisticated automatic ways to extract morphological features and then analyse them statistically in 3-d space, for all 100, 200 subjects. I think that's – I completely, well, we were talking about functional imaging – I see this as even more promising in a way, than functional imaging, to an extent.[116]

Again, note the conflation of the rejection of opticism, and the call for an integration of statistical testing and automation. The system being put in place for cascading data is even more powerful than the imaging technologies that enable the gathering of this information. Once again, a parallel with earlier efforts can be made: in the relation between photography and the archive at the end of the 19th century, 'the central artefact of this system is not the camera but the filing cabinet'.[117] In both instances, faith is placed in the administration of quantified visual difference, rather than in the optical truth of the camera or scanner.

Objectivity and Rhetoric

Before moving on to the final discussion of digital objectivity as potentially characterizing a new type of science, I will note briefly yet another aspect of objectivity which I have not addressed explicitly up to now – objectivity as a rhetorical object. Up to now, the developments described in this paper have involved a medium-sized community within neuroscience. Bowker notes that databases, especially on a large scale, see their classification systems 'increasingly being yanked out of their institutional and political contexts, and applied in other fields with differing ontologies and associations'; and that 'getting any classification systems off the ground is ... always a battle of "winning confidence" and "ingenious presentation"'.[118] The extremes of quantification and standardization that underlie ICBM's objectivity may be helping to win confidence and build trust in databases (to extend Porter's phrase),[119] in a context where disciplines with formerly distant approaches to the brain find that they are encouraged by funding agencies to work together.

Objectivity is at once a potent ideal, a set of methodological prescriptions and an agreed-upon way of working. The case of the digital atlases shows powerfully that the technological fix to the handling of data has had profound epistemological and ontological consequences, rather than just a minor (or even appreciable) impact on efficiency and research management. I would suggest that digital tools might be especially good at providing such interfaces – where disciplines can be translated as various attributes of a voxel; where data, questions, and analysis merge as features of a database; and where yet another algorithm can be implemented to interrogate the data. Digital objectivity, and the various instances of convergence it sustains, may therefore be an important feature of cyberscience.

There are constraints to the building and using of these tools, in which convergence is so crucial. The element of 'administration' is often central to corridor talk about the HBP and neuroinformatics. Proponents and sceptics alike are wary of having these resources overly weighted in the direction of data management, and burdened with stifling standardization.[120] In a sense, this is a well-known issue in sociology of science: the tension between accountability and professional autonomy. The sheer scale of these efforts, however, may mean that the impact of these digital tools goes beyond disciplinary concerns. While the need to develop common standards, and to develop a culture of data sharing, has been flagged as an issue raised by neuroinformatics,[121] other consequences should also be of concern to both practitioners and analysts of cyberscience. The first of these is the obduracy of neuroinformatics resources.[122] While the integration of more data and more types of data increases the power of these atlases, the rigidity of these tools may increase proportionately.[123] These atlases also reinforce the importance of certain features, which I pointed out in the course of this discussion: variability, 'populations', demographic traits, and so on. While provisions are made for ensuring the translatability of many types of data, including new dimensions along the way may not prove feasible, leading either to the abandonment of the database, or to reinforcing the elements that are included as those most important in understanding normality and disease. This has been termed 'hardening of the categories', in the favourite aphorism of scholars of classifications.[124]

Second, part of the rhetoric of cyberscience has been its democratizing effect, in giving greater access to scientific data to a greater number of researchers. Yet, in the case of neuroinformatics, the need for large-scale sampling may be shaping not only the kind of scientific questions that can be answered through neuroinformatics, but also increasing the scope of research projects, with concomitant effect on the size of research groups and institutions that can sustain such projects. This dynamic also seems to be at play in the field of genomics.[125] Finally, the displacement of human intervention in neuroinformatics may also have consequences for the kind of knowledge produced. Up to now, this concern has been voiced as fears that this mode of science will not be driven by 'the questions', but rather pursued as a managerial exercise. As seen in the case of atlases, the displacement of expertise away from an embodied observer has non-trivial consequences for notions of objectivity. If judgement and experience are delegated to technologies in neuroinformatics, it is likely that other notions that have been part of scientific practice and traditionally located in the subject (creativity, understanding, discovery and insight) will also be reshaped by informatics. In this sense, studies of the Human Brain Project, and of cyberscience, may indeed say much about the changing behaviour of scientists.

Notes

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1. James M. Bower, 'What Will Save Neuroscience?', *NeuroImage*, Vol. 4, No. 3 (December 1996), S29-S33.
2. Funds of about $4–5 million were planned for the first call in 1993: see Anon., *Program Announcement*, 'The Human Brain Project: Phase 1 Feasibility Studies', *NIH Guide*, Vol. 22, No. 13 (2 April 1993): <*http://grants.nih.gov/grants/guide/pa-files/PA-93–068.html*>. By 1996, about 60 investigators were supported: Michael F. Huerta and Stephen H. Koslow, 'Opportunities across Disciplinary and National Borders', *NeuroImage*, Vol. 4, No. 3 (December 1996), S4-S6. The HBP budget for FY 2000 is $10.6 million: see Stephen H. Koslow, 'Should the Neuroscience Community Make a Paradigm Shift to Sharing Primary Data?', *Nature Neuroscience*, Vol. 3, No. 9 (September 2000), 865. The report that launched this initiative was published in 1991: Constance M. Pechura and Joseph B. Martin, *Mapping the Brain and its Functions: Integrating Enabling Technologies into Neuroscience Research* (Washington, DC: National Academy Press, 1991). Fears that all funding would be monopolized by this project were expressed at that time and, since then, the project has also had to defend its 'big science' status: see Dominic Purpura,''The Human Brain Project: Priority or Problem?', in Michael F. Huerta and Steven H. Koslow (eds), *Neuroinformatics: An Overview of the Human Brain Mapping Project* (Malwah, NJ: Lawrence Erlbaum Associates, 1997), 13–19; Richard Frackowiak, 'Recreating the Brain Online', *Science*, Vol. 279 (27 February 1998), 1320. The HBP was sometimes identified as a 'big science' project, comparable to the physicists' Super Collider and the Human Genome Project: see Leslie Roberts, 'A Call to Action on a Human Brain Mapping Project', *Science*, Vol. 252 (28 June 1991), 1974; Purpura, op. cit. It has also been deplored that the Decade of the Brain has simply resulted in redistribution of the same funds, with less freedom: Martin Enserink, ''e Zwakke signalen uit Brein 2002', *Zeno*, Vol. 1 (1993), 4–7.
3. The term 'neuroinformatics' is first mentioned in relation to the HBP in an *Addendum* (15 September 1994), to the *Program Announcement*, op. cit. note 2. The word is now very widespread, and this sense of the term, in which informatics are subsumed to the goals of neuroscience, now predominates an earlier sense, in which it referred to a field also known as 'computational neuroscience'.
4. In September 2000, the Vienna joint conference of the Society for Social Studies of Science (4S) and the European Association for Studies of Science and Technology (EASST) hosted panels on cyberscience, an umbrella term meant to encompass the changes in scientific practice brought about by new digital and electronic resources. Evelyn Fox Keller uses the term to refer to the field of computer science, widely defined to include information theory, cybernetics, operations research and computer science: cited in Catherine Waldby, 'The Visible Human Project: Data into Flesh, Flesh into Data', in Janine Marchessault and Kim Sawchuk (eds), *Wild Science: Feminist Readings of Science, Medicine and the Media* (London: Routledge, 2000), 24–38.
5. Both collaboratories and databases were hotly debated in the American Federal research management context in the early 1990s: see Vinton G. Cerf et al., 'Committee on a National Collaboratory: Establishing the User-Developer Partnership', Computer Science and Telecommunications Board, Commission on

Physical Sciences, Mathematics and Applications, National Research Council, *National Collaboratories: Applying Information Technology for Scientific Research* (Washington, DC: National Academy Press, 1993).

6. Pechura & Martin, op. cit. note 2.
7. Final Report of the OECD Megascience Forum Working Group on Biological Informatics (January 1999), 6: <*www.oecd.org/dsti/sti/s_t/act/ms_act.htm*>.
8. See, for example, Joan H. Fujimura and Michael Fortun, 'Constructing Knowledge Across Social Worlds: The Case of DNA Sequence Databases in Molecular Biology', in Laura Nader (ed.), *Naked Science: Anthropological Inquiry into Boundaries, Power and Knowledge* (New York: Routledge, 1996), 160–73, on the use of genetic databases versus 'wet' experiments in the lab, and the respective amount of 'labour' involved. For an analysis of changing styles of writing and data analysis in the social sciences, see Bella Dicks and Bruce Mason, 'Hypermedia and Ethnography: Reflections on the Construction of a Research Approach', *Sociological Research Online*, Vol. 3, No. 3 (1998) <*http://www.socresonline.org.uk/socresonline/3/3/3.html*>; Roger Slack, 'On the Potentialities and Problems of a WWW Based Naturalistic Sociology', *ibid.*, Vol. 3, No. 2 (1998) <*www.[ibid.]/3/2/3.html*>; for an analysis of practices surrounding electronic publishing, see Marcel Lafollette, 'Observations on Fraud and Scientific Integrity in a Digital Environment', *Journal of the American Society for Information Science*, Vol. 51, No. 14 (December 2000), 1334–37. For an attempt at a more integrated approach to the study of these various changes, see the Dutch Institute for Scientific Information (NIWI), 'Exploring the Future of Scholarly Information & Communication', *NIWI Research Programme 2000–2004* (2000), <*http://www.niwi.knaw.nl/nl/research/res_prog.pdf*>.
9. Rob Kling, 'Learning About Information Technologies and Social Change: The Contribution of Social Informatics', *The Information Society*, Vol. 16, No. 3 (July-September 2000), 1–37.
10. Karin Knorr Cetina, *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge, MA: Harvard University Press, 1999); Sharon Traweek *Lifetimes and Beamtimes: The World of High Energy Physics* (Cambridge, MA: Harvard University Press, 1988); Olga Amsterdamska and Anja Hiddinga, 'The Analyzed Body', in John Pickstone and Roger Cooter (eds), *Medicine in the Twentieth Century* (London: Harwood Academic Publishers, 2000), 419–35.
11. Geoffrey C. Bowker, 'Biodiversity Datadiversity', *Social Studies of Science*, Vol. 30, No. 5 (October 2000), 643–83.
12. Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things Out: Classification and Its Consequences* (Cambridge, MA: MIT Press, 1999).
13. Donna J. Haraway, *Modest_Witness@Second_Millennium. FemaleMan©_Meets_OncoMouse™. Feminism and Technoscience* (New York & London: Routledge, 1997), esp. Chapters 4, 5 & 6, 131–213.
14. Waldby, op. cit. note 4.
15. See Irma van der Ploeg, 'Hermaphrodite Patients: In Vitro Fertilization and the Transformation of Male Infertility', *Science, Technology, & Human Values*, Vol. 20, No. 4 (Autumn 1995), 460–81, for an incisive analysis of the subject positions offered to women, foetuses and men in the technologies of reproductive medicine.
16. Linda F. Hogle, 'Standardization Across Non-standard Domains: The Case of Organ Procurement', *Science, Technology, & Human Values*, Vol. 20, No. 4 (Autumn 1995), 482–500.
17. Marc Berg, *Rationalising Medical Work: Decision Support Techniques and Medical Practices* (unpublished PhD thesis, Department of Health Ethics and Philosophy, University of Maastricht, 1995).
18. See Fujimura & Fortun, op. cit. note 8.
19. See Michael Lynch, 'Laboratory Space and the Technological Complex: An Investigation of Topical Contextures', *Science in Context*, Vol. 4 (1991), 51–78.
20. N. Katherine Hayles, 'The Materiality of Informatics', *Configurations*, Vol. 1, No. 1 (Winter 1992), 147–70.

21. Lorraine Daston and Peter Galison, 'The Image of Objectivity', *Representations*, Vol. 40, No. 1 (Fall 1992), 81–128.
22. Ibid., 84–98.
23. Ibid., 82–83.
24. Another main aspect of atlases, and certainly one that is crucial for atlases of the body, is the representation of the normal. Like objectivity, the 'normal' is not a monolithic concept but is, rather, dependent on the institutions, technologies and kinds of measurements made. See Ian Hacking, *Rewriting the Soul: Multiple Personality and the Sciences of Memory* (Princeton, NJ: Princeton University Press, 1995), esp. Chapter 17, 'An Indeterminacy in the Past', 234–57; Alan Sekula, 'The Body and the Archive', *October*, Vol. 39 (1986), 2–64. The involvement of atlases in this process has been analysed in terms of the young male body as the norm, and the female or ageing body as the deviating version: see Susan Lawrence and Kate Bendixen, 'His and Hers: Male and Female Anatomy in Anatomy Texts for US Medical Students', *Social Science and Medicine*, Vol. 35, No. 7 (October 1992), 925–33. Atlases are representations created through (and sustaining) these conventions, though only those concerning objectivity are discussed here.
25. See the website of the NIMH Office for Neuroinformatics at *http://www.nimh.nih.gov/neuroinformatics/index.cfm*
26. Larry Swanson, 'Mapping the Human Brain: Past, Present and Future', *Trends in the Neurosciences*, Vol. 18, No. 11 (November 1995), 471–73. Brain mapping has been called a convergence of disciplines, and characterized as having a multidisciplinary nature: see Peter Fox, 'Human Brain Mapping: A Convergence of Disciplines', *Human Brain Mapping*, Vol. 1 (1993), 1–2; Arthur Toga, 'Editorial', *NeuroImage*, Vol. 1, No. 1 (1992), 1.
27. See Anne Beaulieu, 'The Brain at the End of the Rainbow: Promises of Brain Scanning in the Research Field and in the Media', in Marchessault & Sawchuk (eds), op. cit. note 4, 39–52; Joseph Dumit, 'Desiring a Beautiful Image of the Brain: A Cultural Semiotic Enquiry' (paper presented at the Conference on Visual Representation in Scientific Practice, Gavelston, TX, 28 April-11 May 1994).
28. Jean Talairach and Pierre Tournoux, trans. Mark Rayport, *Co-Planar Stereotaxic Atlas of the Human Brain: 3-Dimensional Proportional System: An Approach to Cerebral Imaging* (Stuttgart: Georg Tieme Verlag, 1988).
29. The Positron Emission Tomography (PET) technique allows the measurement of particular radioactive tracers in the brain. Magnetic Resonance Imaging (MRI) provides scans of the brain without the radiation involved in CT scanning, and is therefore more widely applicable, to 'normal' (non-clinical) subjects, including children, and for repeated scanning.
30. There were hopes that the neuroscientific community would be more successful than the splintered resources of the genomic community, because of the central co-ordination of the efforts by a board representing the granting agencies, which would ensure that the various databases would be built so as to be compatible, and could thus be 'federated': see Peter Fox and Jack Lancaster, 'Neuroscience on the Net', *Science*, Vol. 266 (11 November 1994), 994–96.
31. Japan led the development of the 'Human Frontier Program' (in the late 1980s), which strongly emphasized neuroscience research. The United States also dedicated the decade (in 1990), while the European Union launched its initiative in 1992: F. Pandolfi, 'Inauguration of the European Decade of Brain Research', in J. Mendlewicz, N. Brunello, S. Langer and G. Racagni (eds), *New Pharmacological Approaches to the Therapy of Depressive Disorders* (Basel: International Academy of Biomedical Drug Research, Karger, 1993), 135–38. A number of other countries (Italy, Sweden, The Netherlands, Canada) also launched 'decades' around this time. While thematically linked, the agendas of each initiative differed somewhat. The goals formulated by the European task force for the Decade of Brain research addressed the need for neuroscience to 'reach a "critical mass" of neuroscientists needed to carry out research most efficiently', and be able to compete with the USA: see Alison Abbott, 'Confusion

About Form and Function Clouds Launch of EC's Decade of the Brain', *Nature*, Vol. 359 (24 September 1992), 260; Pandolfi, op. cit.

32. See various histories in Sten Grillner, 'From Ion Channels to Networks and Behaviour: Modelling and Biological Experiments in Interaction', *NeuroImage*, Vol. 4, No. 3 (December 1996), S19-S22; Line Matthiessen, 'Support and Coordination of Neuroscience and Informatics Research in Europe: Research in the Field of Neuroscience under European Union Programs', ibid., S2-S3.
33. Various versions of this narrative can be found in: Floyd Bloom, 'Neuroscience-knowledge Management: Slow Change So Far', *Trends in the Neurosciences*, Vol. 18, No. 2 (February 1995), 48–49; Gwen A. Jacobs, 'Analysis of Information Processing in the Nervous System Using a Database of Identified Neurons', *NeuroImage*, Vol. 4, No. 3 (December 1996), S23-S24; *Program Announcement*, op. cit. note 2; Fox, op. cit. note 26; and Alan Gibbons, 'Databasing the Brain', *Science*, Vol. 258 (18 December 1992), 1872–73. This explosion is often illustrated by tracing the membership of the Society for Neuroscience: less than 400 scientists at a meeting in the early 1970s, then 20,000 in 1991: see Lewis Judd, 'The Decade of the Brain in the United States', in Mendlewicz et al. (eds), op. cit. note 31, 147–50. This narrative continues to appear to the present: see the Neuroinformatics web page at NIMH (op. cit. note 25); and Koslow (2000), op. cit. note 2.
34. Geoffrey Bowker notes that scientists in the field of biology also feel bounded by the amount of literature available to them, even within their own specialty: Bowker, op. cit. note 11, 651. The narrative of the 'crisis' in neuroscience constitutes an interesting contrast to that of the Human Genome Project, where the story of the development of the project, as told by Lois Wingerson, *Mapping our Genes: The Genome Project and the Future of Medicine* (New York: Penguin, 1990) and in the *Human Genome News*, is one of 'individual scientists gradually becoming aware of the surplus value of their combined efforts': see Jose van Dijck, 'Reading the Human Genome Narrative', *Science as Culture*, Vol. 5 (Part 2), No. 23 (1995), 218–47. While they cannot be discussed here, differences in these calls to rationalization should not be glossed over, as they may indicate a variety of configurations of concerns (to move away from judgement, to address managerial concerns, and so on) and of the need for these tools to provide an interface between science and policy. The particular version of the HBP's need for a coordinated effort makes the project less urgent, but might also make it less threatening to scientists who fear imposed standards and control from above – fears which are often heard in discussions of the Human Brain Project (see, for example, Purpura, op. cit. note 2). Fears, and resistance to the imposition of standards and the requirement to make data available in publicly accessible databases (a common practice in many molecular biology settings) are at the root of a controversy currently raging in the functional imaging community: see the Editorial, 'A Debate Over fMRI Data Sharing', *Nature Neuroscience*, Vol. 3, No. 9 (September 2000), 845–46.
35. This is the scenario as articulated by Bloom, op. cit. note 33, and paraphrased in Huerta & Kuslow, op. cit. note 2, S4.
36. Bloom, op. cit. note 33; Michael F. Huerta, Stephen H. Koslow and Alan Leshner, 'The Human Brain Project: An International Resource', *Trends in Neurosciences*, Vol. 16, No. 11 (November 1993), 436–38; Jerome Cox, 'Foreword', in Huerta & Koslow (eds), *Neuroinformatics*, op. cit. note 2, vii-x.
37. In preparation for the Decade of the Brain launch, a number of reports had been commissioned. One of these was sponsored by the National Institute of Mental Health, and was written by Stephen H. Koslow (1989). The report addressed the development of a 'National Neural Circuitry Database', an idea that was originally proposed in the late 1970s but abandoned because of a lack of technological means to achieve it (see Huerta, Koslow & Leshner, op. cit. note 36) and lack of consensus about the features to be included (see Cox, op. cit. note 36). Following Stephen H. Koslow's report, a committee was set up by the NIMH to address the 'feasibility and

utility of incorporating computer technology into the basic and clinical neurosciences in order to enhance research progress' (Pechura & Martin, op. cit. note 2, v).

38. Pechura & Martin, op. cit. note 2, 21–22.
39. Huerta, Koslow & Leshner, op. cit. note 36.
40. Proponents of neuroinformatics have sought and established links internationally. In 1995, a workshop on neuroinformatics was held through the US-EC Task Force on Biotechnology Research. Calls of the American-based project for 'the integration of research from the molecular and cellular levels up to the system level' were echoed at this meeting: Matthiessen, op. cit. note 32. On the international scene, in the late 1990s, the OECD Megascience Forum endorsed a proposal from the USA to establish a 'Biological Informatics Working Group', with neuroinformatics as one of its subgroups.
41. Gibbons, op. cit. note 33, 1873.
42. Donna Haraway, *Simians, Cyborgs and Women: The Reinvention of Nature* (New York: Routledge, 1991), esp. Chapter 9, 'Situated Knowledge: The Science Question in Feminism and the Privilege of Partial Perspective', 183–220.
43. Pechura & Martin, op. cit. note 2, 12.
44. Bowker, op. cit. note 11, 677.
45. John Mazziotta and Arthur Toga, 'Speculations about the Future', in Arthur Toga and John Mazziotta (eds), *Human Brain Mapping: the Methods* (San Diego, CA: Academic Press, 1996), 445–56, at 455.
46. Arthur Toga and Paul Thompson's web page, 'Multimodal Brain Atlases', Laboratory of Neuroimaging: <*http://www.loni.ucla.edu/~thompson/whole_atlas.html*> (accessed 12 January 2001).
47. These quotations are respectively from Arthur Toga and John Mazziotta, 'Introduction to the Cartography of the Brain', in Toga & Mazziotta (eds), op. cit. note 45, 3–25, at 13; and Per Roland and Karl Zilles, 'Brain Atlases – a New Research Tool', *Trends in Neurosciences*, Vol. 17, No. 11 (November 1994), 458–67, at 466.
48. Edward R. Tufte, *The Visual Display of Quantitative Information* (Cheshire, CT: Graphic Press, 1983); Denis Wood, *The Power of Maps* (London: Routledge, 1993); David Turnbull (with Helen Watson and the Yolngu Community at Yirrkala), *Maps are Territories: Science is an Atlas* (Geelong, Victoria: Deakin University Press, 1989; Chicago, IL: The University of Chicago Press, 1993).
49. Alan Evans, Sean Marrett and Terry Peters, 'Anatomical-functional Correlative Analysis of the Human Brain Using Three-Dimensional Imaging System' (Abstract), *Proceedings of the International Society for Optical Engineering, Medical Imagery*, Vol. III, No. 264 (1989), 274; Alan Evans, Sean Marrett, Peter Neelin, Keith Worsley, Weiquan Dai, Sylvain Millot, Ernst Meyer and Daniel Bub, 'Anatomical Mapping of Functional Activation in Stereotactic Coordinate Space', *NeuroImage*, Vol. 1, No. 1 (1992), 43–53.
50. The atlases could also be improved by being based on imaging, since atlases arising from invasive techniques, like intra-operative stimulation, could not be relied on to provide data about the 'intact' brain. Furthermore, these techniques are only used on subjects that have cerebral abnormalities, so that data from these sources can only be compared with, but should not be considered typical of, normal brain structure and function: see John Mazziotta, Arthur Toga, Alan Evans, Peter Fox and Jack Lancaster, 'Atlases of the Human Brain', in Huerta & Koslow (eds), *Neuroinformatics*, op. cit. note 2, Chapter 8, 255–308.
51. Researchers from three more institutions have joined the efforts of the Consortium to contribute specific expertise for their next programme grant to be funded by the Human Brain Project (1998–2003): Albert Einstein College, Heinrich-Hein University of Dusseldorf, and Stanford University.
52. This atlas can be viewed at <*http://www.bic.mni.mcgill.ca/cgi/icbm_view/*>. It is alternately described as being composed of 302, 305 or 450 brains: 450 is the expected goal, the other two numbers appearing seemingly at random. This probably reflects the data management issues that arise when trying to discipline data for

integration, and the difficulty in working with a system that gets updated all the time, while trying to use it as a reference.

53. Mazziotta et al., op. cit. note 50, 291.
54. ICBM, *A Probabilistic Reference System for the Human Brain. Renewal Application to the Human Brain Project: Phase 1* (unpublished Research Grant Application, 1997). Large portions of this document can be consulted online at the ICBM website: <*www.loni.ucla.edu/ICBM*>.
55. Mazziotta et al., op. cit. note 50, 258.
56. See Trudy Dehue, 'Deception, Efficiency and Random Groups: Psychology and the Gradual Origination of the Random Group Design', *Isis*, Vol. 88 (1997), 653–73, on the careful randomization of the social sciences. While this was not an explicit methodological concern of the researchers, on the other hand, a kind of spontaneous or natural 'randomization' was expected to occur, as the different centres selected from their local environment. Researchers claimed that it would not aim to characterize an entire population, but to demonstrate the feasibility of doing so. But eventually, the data will 'be representative of the population with regard to gender and race and will specifically examine the effects of handedness and gender on structural and functional brain variance' (ICBM, op. cit. note 54, 255). Appealing to the first, prototypical phase of a tool is a common strategy in the development of new technologies. Requirements to address sociologically important questions are minimized and delegated to a future, unspecified time period, while the current appeal of the potential of the tool is maximized. Here too, the notion of a population-based atlas evokes population-wide applicability and relevance of such projects: for an exposition of the prototype strategy, see Jessika van Kammen, *Conceiving Contraceptives The Involvement of Users in Anti-fertility Vaccines Development* (unpublished PhD thesis, Department of Science and Technology Dynamics, University of Amsterdam, 2000). Other differences, such as race, weight or height are expected to be 'randomized' within the data set.
57. Anne Harrington, *Medicine, Mind and the Double Brain: A Study in Nineteenth-century Thought* (Princeton, NJ: Princeton University Press, 1987).
58. For the relation of brain scanning to notions of self, see: Joseph Dumit, 'A Digital Image of the Category of the Person: PET Scanning and Objective Self-Fashioning', in Gary Lee Downey and Joseph Dumit (eds), *Cyborgs and Citadels: Anthropological Interventions in Technoscience* (Santa Fe, NM: School of American Research, 1997), 87–128; Anne Beaulieu, *The Self on Screen* (unpublished manuscript, Department of Psychology, University of Bath, 2001). For the notion of 'convergence', see Bowker, op. cit. note 11, 659; and Geoffrey C. Bowker, *Science on the Run: Information Management and Industrial Geophysics at Schlumberger, 1920–1940* (Cambridge, MA: MIT Press, 1994), 162–66.
59. Susan Leigh Star, *Regions of the Mind: Brain Research and the Quest for Scientific Certainty* (Stanford, CA: Stanford University Press, 1989). A number of examples of 'multiple specimens use' can be found through this book.
60. Per Roland, C. Graufelds, J. Wahlin, L. Ingelman, M. Andersson, A. Ledberg, J. Pedersen, S. Akerman, A. Dabringhaus and Karl Zilles, 'Human Brain Atlas: For High-Resolution Functional and Anatomical Mapping', *Human Brain Mapping*, Vol. 1 (1994), 173–84.
61. Eliminating the embodied user may on occasion be a displacement rather than a disappearance: instead of a trained anatomist, the use, or at least installation, of these programmes might require an embodied software expert.
62. Pechura & Martin, op. cit. note 2, 11, 14. As noted above, some of these features are traditional categories of neuroscience specifically, or of modern biomedicine more generally.
63. ICBM, op. cit. note 54, 153.
64. Up to now, age has been the most determinant feature, because of the research practices of recruiting young volunteers, and because of the clinical conditions investigated in relation to the atlas. Young brains were selected in the first instance,

partly to provide age-matched controls for the activations studies, which often use university students as subjects. The age range for the first phase was from 18 to 40, and this will be extended to 90, as the Consortium focuses on studies of diseases of old age, 'because [the age range] conforms with the normal control population recommendations for the study of Alzheimer's and degenerative diseases of the brain'. This will also allow the comparison of data across seven decades and determine variance as a function of age: ICBM, op. cit. note 54, 248.

65. Mazziotta et al., op. cit. note 50, 260.
66. Francis Crick and Edward Jones, 'Backwardness of Human Neuroanatomy', *Nature*, Vol. 361 (14 January 1993), 109–10; Albert M. Galaburda, Marjorie LeMay, Thomas L. Kemper and Norman Geschwind, 'Right-Left Asymmetries in the Brain', *Science*, Vol. 199 (24 February 1978), 852–56.
67. Galaburda et al., ibid., 856. I briefly return to this issue in the Conclusion.
68. Mazziotta et al., op. cit. note 50, 288.
69. Quoted in Sekula, op. cit. note 24, at 47.
70. Just as statements about the number of brains in the average atlas vary, so do estimates of the number of centres using this atlas: numbers range from 35 centres (Mazziotta et al., op. cit. note 50, 561) to 100 in ICBM's Proposal (op. cit. note 54, 208).
71. Peter Fox and Marty Woldorff, 'Integrating Human Brain Maps', *Current Opinion in Neurobiology*, Vol. 4 (1994), 151–56.
72. This can be found in Greg Ward, *Internal Guide to ICBM* (unpublished manuscript, Brain Imaging Centre, Montreal Neurological Hospital, 1996); Maziotta et al., op. cit. note 50; Richard Frackowiak, Karl Friston, Christopher Frith, Ray Dolan and John Mazziotta (eds), *Human Brain Function* (San Diego, CA: Academic Press, 1997); Toga & Mazziotta (eds), op. cit. note 45. Another aspect of the perceived greater complexity of the brain was also formulated by contrasting terrestrial and cerebral cartography: structures in the depth of the brain (cortical folds) must also be represented, hence showing surfaces as problematic, since they do not reveal these, leading to recommendations for 3D representations: see Swanson, op. cit. note 26.
73. Toga & Thompson, loc. cit. note 46 (accessed 12 January 2001).
74. Mazziotta et al., op. cit. note 50, 259.
75. George Canguilhem, trans. Carolyn Fawcett, *On the Normal and the Pathological* (Dordrecht: Reidel, 1978), 70.
76. Bowker, op. cit. note 11, 646, 669; see also note 52.
77. Another interesting line of inquiry here would be to follow the process by which imaging data has become part of the required evidence to be produced in clinical trials.
78. The MNI space encompasses only the brain, thereby ignoring lesions in the spinal chord. This is but one unintended consequence of brain mapping's focus on the cortex.
79. MRI detects a signal at the molecular level, and these signals can be used to contrast different substances that make up the brain and head.
80. Anja Hiddinga, *Changing Normality: Pregnancy and Scientific Knowledge Claims 1920–1950, with Special Reference to the USA* (unpublished PhD thesis, Department of Science and Technology Dynamics, University of Amsterdam, 1995).
81. Bruno Latour, 'Drawing Things Together', in Michael Lynch and Steve Woolgar (eds), *Representation in Scientific Practice* (Cambridge, MA: MIT Press, 1990), 19–68.
82. ICBM, op. cit. note 54, 210.
83. Nancy C. Andreasen, Stephan Arndt, Victor Swayze II, Ted Cizadlo, Michael Flaum, Daniel O'Leary, James C. Erhardt and William T.C. Yuh, 'Thalamic Abnormalities in Schizophrenia Visualized through Magnetic Resonance Image Averaging', *Science*, Vol. 266 (14 October 1994), 294–98, at 295.
84. Daston & Galison, op. cit. note 21, 94. As anatomy shifted from a description of structures to an anatomy based on interpretation of symptoms and their relation to anatomical lesions, medical atlases came to represent these new relations in

'characteristic' representations, so that they might be learned and recognized by medical practitioners: see Audrey B. Davis, *Medicine and Its Technology: An Introduction to the History of Medical Instrumentation* (Westport, CT: Greenwood Press, 1981), esp. 91, 155.

85. Alongside this approach to objectivity through automation, I also observed a number of (local?) strategies for using or checking on the automated process. Some types of scans were expected to be processed unsuccessfully, because they had been made according to non-conforming scanning procedures (for example, they are clinical and not research scans), and some types of brains were expected to fail (because of pathology). Users of automated software would call up images from different stages of analysis, to run little tests to check what had been changed in the image data. In cases where the reasons for failures could be typified, attempts to deal with these structurally were made.
86. Bowker, op. cit. note 11, 655.
87. The determination of common standards of normality involves agreeing on a measurement space, as amply discussed above. Another aspect of this process is the calibration of instruments used in measurement. While this aspect will not be discussed here for the sake of clarity and brevity, the calibration of instruments through the use of 'phantoms' (either real, standard objects, or else data-sets to be processed) which enable different centres to evaluate the performance of their instrumentation, is part of the work pursued under HBP grants, and also has some roots in the work of neuroimagers in the 1980s. See: John Mazziotta and Stephen Koslow, 'Assessment of Goals and Obstacles in Data Acquisition and Analysis from Emission Tomography: Report of a Series of International Workshops', *Journal of Cerebral Blood Flow and Metabolism*, Vol. 7 (1987), A51-A56; Stanley I. Rapoport, 'Discussion of PET Workshop Reports, Including Recommendations of PET Data Analysis Work Group', *ibid.*, Vol. 11 (1991), A140-A146. See also Joseph O'Connell, 'Metrology: The Creation of Universality by the Circulation of Particulars', *Social Studies of Science*, Vol. 23, No. 1 (February 1993), 129–73, at 130–36, for a discussion in a context of bodily measurements/biometrics; and Knorr Cetina (52–55) and Traweek (46–73), opera cit. note 9, for further discussions of calibration in another physics instrumentation context.
88. Huerta & Koslow (1996), op. cit. note 2, S5.
89. ICBM, op. cit. note 54, 211.
90. Paul Thompson, David McDonald, Michael S. Mega, Alan Evans and Arthur Toga, 'Detection of Abnormal Brain Structures with a Probabilistic Atlas of Cortical Surfaces', *Journal of Computer Assisted Tomography*, Vol. 21 (1997), 567–81, at 579.
91. A level of 'cognitive familiarity' has been shown to play a rôle in circulation of systems of classification and knowledge claims: see Hiddinga, op. cit. note 80, esp. 184–89. For an extensive elaboration of how to study 'cognitive familiarity', see also Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago, IL & London: The University of Chicago Press, 1997). By producing results in a form clinicians already use, these kinds of atlases (effectively databases of scans) are expected to be more acceptable to these users.
92. ICBM, op. cit. note 54, 150–55.
93. Ibid., 151.
94. Bowker, op. cit. note 11, 666–67.
95. Daston & Galison, op. cit. note 21; Michael Lynch, 'The Externalised Retina: Selection and Mathematization in the Visual Documentation of Objects in the Life Sciences', in Lynch & Woolgar (eds), op. cit. note 81, 153–86.
96. Roland & Zilles, op. cit. note 47, 458.
97. To compare these two archives is to link analytically two historically distant projects that both aimed at finding distinction between groups. The politics of the first, so clear to us in hindsight and so broadly condemned, are not meant to indict the second case but, rather, by juxtaposing the first with its highly exposed politics to the second,

the aim is to highlight the need for an equally careful functional and political analysis of contemporary archives.

98. Sekula, op. cit. note 24, 17ff. The photographic archive arises in conjunction with the emerging social science of criminology and the professionalization of police work.
99. See John Tagg, 'Power and Photography: Part One, A Means of Surveillance: The Photograph as Evidence in Law', *Screen Education*, Vol. 36 (Autumn 1980), 17–55, and 'Part Two, A Legal Reality: The Photograph as Property in Law', *ibid.*, Vol. 37 (Winter 1980), 17–27; Sekula, op. cit. note 24.
100. This is literally so: Bertillon's system was developed for the application of anthropometry to police work, namely the catching of criminals.
101. Sekula, op. cit. note 24, 26.
102. According to Sekula (ibid., 53–55), the downfall of these efforts to develop systems of photographic documentation and administration was caused by the cumbersome nature of the processing of suspects, the rise of fingerprinting as an easier system and, more generally, the demise of an optical model of empiricism.
103. Daston & Galison, op. cit. note 21, 84–85. See Bernike Pasveer, 'Knowledge of Shadows: the Introduction of X-ray Images in Medicine', *Sociology of Health and Illness*, Vol. 11, No. 4 (December 1989), 360–81; Pasveer describes this as a socially-constructed (not mainly a cognitive) process of meaning-making, where context and content are only progressively shaped as (separate) entities. For other descriptions of learning to see and seeing socially, see also: Charles Goodwin, 'Seeing in Depth', *Social Studies of Science*, Vol. 25, No. 2 (May 1995), 237–74; Goodwin, 'Professional Vision', *American Anthropologist*, Vol. 96, No. 3 (September 1994), 606–33.
104. Arthur Toga and Paul Thompson, 'Brain Atlases and Registration', in Isaac Bankman (ed.), *Handbook of Medical Image Processing* (San Diego, CA: Academic Press, 1998), 1–19, at 6.
105. Mazziotta et al., op. cit. note 50.
106. See Anne Beaulieu, *The Space inside the Skull: Digital Representations, Brain Mapping and Cognitive Neuroscience in the Decade of the Brain* (unpublished PhD thesis, Department of Science and Technology Dynamics, University of Amsterdam, 2000), 166–82.
107. Jonathan Crary, *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century* (Cambridge, MA: MIT Press, 1992).
108. Bowker & Star, op. cit. note 12, 46–49.
109. For an analysis of these techniques of objectivity, see Trudy Dehue, 'From Deception Trials to Control Reagents: The Introduction of the Control Group about a Century Ago', *American Psychologist*, Vol. 55, No.2 (February 2000), 264–68; Lorraine Daston, 'Objectivity and the Escape from Perspective', *Social Studies of Science*, Vol. 22, No. 4 (November 1992), 597–618; Alain Desrosières, *La Politique des Grands Nombres: Histoire de la Raison Statistique* (Paris: La Découverte, 1993).
110. A term coined to characterize WWW advances: see Daniel Atkins, 'Electronic Collaboratories and Digital Libraries', *NeuroImage*, Vol. 4, No. 3 (December 1996), S55-S58.
111. Latour, op. cit. note 81, 52–60. This cascade is not unidirectional, however, since the use and application of the atlases rely on being able to relate to the individual case. Clinical relevance constitutes an important element in this research. This has not always been the case; the clinical relevance of neuroscience seems to have been an important trend in the increased public visibility of the neurosciences in the 1990s: see Edward G. Jones, 'Neuroscience in the Modern Era', *Neuroscience Newsletter*, Society for Neuroscience (January/February 2000), 5–11.
112. Roland & Zilles, op. cit. note 47, 459.
113. Gordon M. Shepherd, Jason S. Mirsky, Matthew D. Healy, Michael S. Singer, Emmanouil Skoufos, Michael S. Hines, Prakask M. Nadkarni and Perry L. Miller, 'The Human Brain Project: Neuroinformatics Tools for Integrating, Searching and Modelling Multi-Disciplinary Neuroscience Data', *Trends in Neurosciences*, Vol. 21, No. 11 (November 1998), 460–68.

114. Fujimura & Fortun, op. cit. note 8.
115. Lynch, op. cit. note 19, 55.
116. The fieldwork material used in this article comes from my two periods of study in two leading functional imaging laboratories, and from observations and interviews at various international events in the brain-mapping community (1996–2001). Much of the information which informs this study is drawn from discussions and more formal in-depth interviews done during a 6-month period of fieldwork in two laboratories in Europe (lab E) and in North America (lab NA). The North American lab was actively involved in databasing endeavours. Permission to tape-record the interviews was granted, and anonymity was promised to the interviewees. They were described in terms of their seniority and disciplinary background; the latter is relevant to understanding the new field of brain mapping since, until very recently, no one had received their education or primary training in this field. This verbatim quotation is from an interview with a senior researcher, trained as a neurophysiologist (lab NA, December 1997).
117. Sekula, op. cit. note 24, 55.
118. Bowker, op. cit. note 11, 648, 652.
119. Theodore Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton, NJ: Princeton University Press, 1996).
120. This element has recently become much more public with the announcement of a new database, linked to publishing in the *Journal of Cognitive Neuroscience*, so that submissions to the journal will entail submission of data to the database. For a glimpse of these issues in print, see Editorial, op. cit. note 34.
121. Fox & Lancaster, op. cit. note 30; Shepherd et al., op. cit. note 113; Michael Chicurel, 'Databasing the Brain', *Nature*, Vol. 406 (24 August 2000), 822–25.
122. As well, even those who embrace and contribute to the project of the ICBM sometimes resist the full application of the logic of a probabilistic database; the users of these atlases require a certain obduracy. While praised for having 'open data structures', and therefore continuously improving statistics, a system of 'quarantine' has been developed around the ICBM database, so that users might have a reasonably stable basis on which to perform analyses. This requires careful weighting of the potential benefits of improvements to the analysis software (the elements of the pipeline), and the need for robustness and stability of a research tool in the course of pursuing a research project. The structure of research and scientific publishing may come to change to fit this type of tool but currently, the traditional data-gathering, analysis and paper-writing cycle, lasting a few months, does not accommodate frequent update of tools.
123. Other projects in the HBP have opted for an object-based structure, where links between units of knowledge are looser, conceptually closer to the traditional 'encyclopaedia', with its entries on various kinds of topics, than these 'atlases', which rely on an ordered data set.
124. This is an epigram to a chapter in Haraway, op. cit. note 13, 131, also noted in Bowker & Star, op. cit. note 12, and credited by Haraway to Helen Watson-Verran, 'Renegotiating What's Natural' (paper read at the Society for Social Studies of Science [4S] Conference, New Orleans, 12–15 October 1994).
125. Brian Balmer, 'Managing Mapping in the Human Genome Project', *Social Studies of Science*, Vol. 26, No. 3 (August 1996), 531–73.

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