Beyond the Neuro-realism Fallacy:
From John Mallard's Hand-painted MRI Image of a Mouse to BioArt Scenarios

Believed by Aristotle to be a cold sponge mopping up the heat generated by our thinking and feeling heart, the brain appeared as a lifeless, bloodless object to the touch, its internal workings unavailable to our sight.[1] For centuries, from Antiquity to the modern age, medical practice has mainly studied life via death through dissection. For example, exploring the brain was possible only once the brain's internal workings stopped or by means of three-dimensional models that provided an effective representation to be used for research and teaching purposes.[2] In the late 19th century, tissue staining techniques and microscopy enabled the identification of brain cells, thus allowing Golgi and Cajal to see structure inside this organ.[3] Since then, increasingly sophisticated techniques have allowed us to visualise the brain in action. The move from physical, three-dimensional models to digital computer simulations encouraged a visual rather than tactile engagement with the brain.[4]

At the forefront of the development of one of the most important diagnostic imaging technologies of the 20th century, John Mallard, Professor of Medical Physics at the University of Aberdeen from 1965 to 1992, argued:

> [I]t is important to realise that imaging is not just a series of pretty pictures; it is an array of measurements, and the images are important because they make it possible for each patient

[1] Aristotle, *Parts of Animals. Movement of Animals. Progression of Animals*, translated by A.L. Peck, E.S. Forster (Cambridge, MA: Harvard University Press, 1937).

[2] Given that throughout the Middle Ages human dissection was restricted, the main tool for studying and representing the brain was diagrammatic drawing rather than direct observation. From the Renaissance onwards, the study of the brain thrived thanks to dissections of cadavers in anatomical theatres as, for example, the atlas *De Humani Corporis Fabrica* produced in 1543 by the Flemish anatomist Andreas Vesalius. On the culture of dissection see Johnathan Sawday, *The Body Emblazoned: Dissection and the human body in Renaissance culture* (London: Routledge, 1995).

[3] Santiago Ramón y Cajal (1852-1934) is regarded as the father of modern neuroscience. With tremendous talent for drawing, he was able to create detailed drawings of the structure of the nervous system observed through the microscope, formulating theory of the brain as an organ comprising individual nerve cells, the neurons. He shared the Nobel Prize in 1906 with his rival Camillo Golgi (1843-1926).

[4] Soraya De Chadarevian, Nick Hopwood, *Models. The Third Dimension of Science* (Stanford: Stanford University Press, 2004). On the enactment of models in molecular biology laboratories see Natasha Myers, *Rendering Life Molecular. Models, Modelers, and Excitable Matter*, (Durham and London: Duke University Press, 2015). On the history of the different models and metaphors used to represent and investigate the brain see Cornelius Borck "Toys are Us. Models and Metaphors in Brain Research" in *Critical Neuroscience: A Handbook of the Social and Cultural Contexts of Neuroscience*, edited by Suparna Choudhury, Jan Slaby (London: Blackwell, 2011), pp. 111-133.

> to act as their own biological normal: both the normal and the pathology are seen on the same image at the same time.[5]

This is an excerpt from an interview in which Mallard describes the steps that transformed Magnetic Resonance Imaging (MRI) into a clinically viable technique for visualizing the body. The different stages included, as discussed later in the article, the first diagnostically useful MRI image of a dead mouse (1974), the development of the spin-warp method for translating raw data into images (1980), and the building of the world's first whole-body MRI scanner, which entered service at Aberdeen Royal Infirmary in 1980. In this quoted passage Mallard points out three aspects crucial to biomedical imaging. First, images are obtained through data re-construction. Second, biomedical images are a source of information on the patient as a whole. Third, the development of biomedical imaging is inextricably linked to problems of image interpretation and visualisation.

The difficulties related to the transformation of neurological data into a visual output have been at the core of both scholarly debate and artistic practices that engage with the neurosciences. It is through images of the brain and brain scans that the culture and politics of neurosciences becomes visible, solidifies, and spreads across the wider public arena beyond the closed circuit of neuroscientific discourse. This process gives birth to neuroculture: "the incorporation of neuroscience knowledge into our life, culture and intellectual discourses."[6] Since the so-called 'Decade of the Brain' in the 1990s, the images produced through brain imaging techniques have captured the public imagination: the possibility to visualize the human brain and hence to grasp the materiality of thinking seemed possible as never before. Through visual imagery, mass media and popular scientific magazines the concept of self has been presented as if it were increasingly dependent on the biology of the brain, to the point where the category of personhood has been

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[5] John R. Mallard, "A Brief Personal Account of the Aberdeen Story – with particular reference to SPECT and MRI," Academic/Clinical/ Practical Activities and Achievements, 1993, *17: 5*,176-179, p. 178.

[6] Giovanni Frazzetto, Suzanne Anker, "Neuroculture," *Nature Reviews Neuroscience*, 2009, *10*, 815-821, p. 819. On neurocultures, see also Francisco Ortega, Fernando Vidal (eds.), *Neurocultures: glimpses into an expanding universe*, (Frankfurt am Main et al.: Peter Lang, 2011).

substituted by *brainhood*, the ontological belief for which "the brain is the only part of the body we need in order to be ourselves."[7] *Brainhood* is a way to organise a specific politics of the subject, that is a politics centered around the effort to articulate subjectivity by drawing upon both neurosciences and the neurological.[8] This emphasis on the brain becomes part of a new style of neuro-scientific thought affecting areas of knowledge production such as neuro-aesthetics, neuro-marketing, neuro-literary criticism, neuro-law and, for some, even the way in which subjectivity, ethics, politics are conceived.

This article focuses on the visual component of the *brainhood* ideology, and on to its ties with the *neuro-realism* fallacy discussed by Joseph Dumit in his examination of brain imaging. Neuro-realism is the belief that brain scans are the visual evidence of brain activity despite the complexity inherent not only to data acquisition but also to the actual image creation.[9] This fallacy is reinforced in visual practices by use of the extreme image, which is the rendering of neuroscientific scan-data into visually striking and persuasive brain images presented as if they were a direct material index of the analogue magnetic signal.

If visually-mediated neuro-realism is a fallacy of neurosciences, are artists who work on and with the tools of neurosciences also reproducing it? Neuroscience-based or inspired artistic interventions have certainly the merit of taking brain imaging outside the scientific laboratory into the wider public arena. However, it is to be determined whether these artistic practices are able to put forward a critique of the brain-self consubstantiality and challenge the politics of neurologisation that accompanies it. Are artists tracing configurations of subjectivity alternative to the cerebral subject by creating another politics of the neural image, by creating a different

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[7] Fernando Vidal, "Brainhood, Anthropological Figure of Modernity," *History of the Human Sciences*, 2009, *22:1*, 5-36, p. 6.

[8] On the neurologisation of subjectivity see Jan De Vos, *The Metamorphoses of the Brain – Neurologisation and its Discontents* (London: Palgrave, 2016).

[9] Joseph Dumit, "How (Not) to Do Things with Brain Images," in *Representation in Scientific Practice Revisited*, edited by Catelijne Coopmans, Janet Vertes, Michael Lynch, and Steve Woolgar (Cambridge and London, the MIT Press, 2014), pp. 291-313.

iconography of the brain? Or do they simply carry the laboratory-stabilized image interpretations out into the world?

In order to answer those questions, this article follows two trajectories which are based on the study of visual practices inside the laboratory and in the art field, respectively. The first trajectory, which springs from Mallard's reflections around data visualisation problems in biomedical imaging, examines how raw data are transformed into images, highlighting possibilities and problems in the visualisation pipeline from the analogical signal to the digital image. This historical-epistemological investigation is crucial for understanding the neuro-realism fallacy, which is grounded in brain scans.[10] The second trajectory pertains to the artworld. Certain neuroscience-based art practices are able to foster a counter politics of the neural image alternative to the one put forth within the trope of the cerebral subject.

This alternative politics of the neural image is not an exclusive prerogative of artists. Physicist Mallard was by necessity attentive to the construction of visual practices and their meaning. The neuro-realism fallacy is not the fate of neurosciences when the scientific community attends reflexively to the historical epistemology of brain imaging.[11] Mallard's history of the creation of the first clinically useful MRI image shows how the transformation of data into an image was never taken for granted in the initial development of MRI. When the procedure for transforming raw data into images became standardised it was no longer subject to further examination and questioning. Letting those laboratory micro-histories to emerge, enables us to envisage a possible resistance to the neuro-fallacy from *within* the neurosciences. The aim is to

[10] According to Hans-Jörg Rheinberger historical epistemology examines the technical, cultural, historical, social conditions under which the process of knowledge creation takes place. It does not look at knowing subjects and knowable objects as two separate entities, but it examines the space "in-between" them. Hans-Jörg Rheinberger, "Was ist historische Epistemologie?", Colloquium des Max-Planck-Instituts für Wissenschaftsgeschichte, Berlin, Quoted in: Bernhard J. Dotzler, Henning Schmidgen, "Einleitung zu einer Epistemologie der Zwischenräume", in *Parasiten und Sirenen* (Bielefeld: transcript Verlag, 2008), pp. 7-18.

[11] See, for example, Cornelius Borck, "Recording the Brain at Work: The Visible, the Readable, and the Invisible in Electroencephalography," *Journal of the History of the Neurosciences*, 2008, *17*, pp. 367–379.

contribute to further developing the project of a critical neuroscience whose goal is the engagement with the material sites, discourses and practices that re-configure the neurosciences in relation to the human lifeworld.[12]

The article is organised in two sections. The first one discusses the procedure for obtaining MRI brain scans from data, starting off from Mallard's first diagnostically useful MRI image. The technical explanation foregrounds the examination of the neuro-realism fallacy. The visual component of the neuro-realism fallacy, which is embodied by brain scans, is discussed in relation to Wilfrid Sellars' distinction between the scientific and the manifest image.[13] These should not be understood as two material pictures, but rather as two distinct frameworks for describing subjectivity in relation to the world. Sellars argues that the manifest and the scientific image can be brought together into a single stereoscopic vision. Some artists, as I will discuss, attempt to adopt a stereoscopic vision to challenge the neuro-realism fallacy.

The second section of the article offers a critical analysis of selected works from late twentieth century to early twenty-first century art-neuroscience collaborative projects using brain scans or living neurons. Attention will be paid to the material elements of neuroscientific research that are (or are not) re-mediated by artists, showing how these artworks are not merely means to engage the wider public with the neuroscientific discourse; Rather they are capable of questioning the spell exercised by the extreme image which is one of the incarnations of the neuro-realism fallacy. As I will argue, neuroscience-art projects can enable us (or not) to foster and maintain a stereoscopic vision in the way in which we approach the conundrum of what it is like to be both a biological organism made up of molecules, neurons, cells, and an entity equipped with intentionality, desires, thoughts, values.

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[12] On the project for a critical neuroscience see Suparna Choudhury and Jan Slaby (eds.), *Critical Neuroscience* (Cit. note 4). On the conditions of possibility of a critique of neuroscience see Jan de Vos, Ed Pluth (eds.), *Neuroscience and Critique: Exploring the Limits of the Neurological Turn* (New York and London: Routledge, 2015).

[13] Wilfrid Sellars, "Philosophy and the Scientific Image of Man" in *Science, Perception and Reality* (Routledge & Kegan Paul Ltd; London, and The Humanities Press: New York, 1963), pp. 1-40.

I. History and Epistemology of Brain Scans: from Mallard's Hand-painted MRI Image to Sellars' Myth of the Given

The history of the first diagnostically useful MRI image of a dead mouse suggests the epistemological role played by biomedical pictures. Back in the 1970s, the main protagonists of the story were John Mallard, Head of the Biomedical Physics Department at the University of Aberdeeen, Jim Hutchinson, scientific lead of the researchers group, Bill Edelstein, a young postdoctoral scientist involved in the project, and, of course, the dead mouse. Like the majority of scientific breakthroughs and discoveries, the development of MRI, involving different scientific laboratories and research teams across the UK, has not been a linear one.[14] This story combines an image with technologies (MRI and paint), people (the researchers involved in the research and the potential patients benefiting from it), the experimental subject (the mouse), a laboratory setting, and funding.

Mallard and his team understood the potential of a medical application of MRI and in the early 1970s they started to put together equipment to measure magnetic resonance signals from hydrogen in tissue samples. In those same years, two scientists in the United States, Raymond Damadian and Paul Lauterbur, demonstrated, respectively, that magnetic resonance signals from hydrogen could differentiate between normal and cancerous tissues in small samples and that spatial information could be obtained from the magnetic resonance signals. Mallard and his team managed to combine those two achievements in the 1974 image of the mouse, the first ever MRI picture which demonstrated a physiological change. (Fig. 1 HERE).

[14] Some of the controversies related to the different trajectories of the invention of MRI are recounted in M. Joan Dawson, *Paul Lauterbur and the Invention of MRI* (Cambridge MA: the MIT Press, 2013).

Biomedical images like this one need to be read in order to be understood. The image depicts the relaxation time variation (T1) of the water protons in tissue samples that could highlight physiological changes in tissues, such as the broken neck of a mouse. The matrix of numbers (raw data) of these T1 values was printed out on paper and then hand-painted into a location grid. The contours of the mouse were an artistic license; the colours were chosen to highlighting the different areas and physiological changes. They were chosen as an initial convention, such as the white used to represent the "noise" in the image. For those familiar with its context the MRI mouse image showed regions of oedema where the animal's neck had been broken, thus making it the first diagnostically useful MRI image. The projection reconstruction method used for imaging the dead mouse worked only for bodily parts that were not moving. This method was then superseded by the spin-warp method in the 1980s, a much more robust way of encoding spatial information and thus of producing artefact-free images. The spin-warp method is now a standard procedure worldwide.

This hand-painted image reminds us of two crucial issues in biomedical imaging. First, this image points at the centrality played by human eyes and hands even in an age increasingly characterised by the pervasive computerization of data imaging and visualizing.[15] Second, it is a reminder of the frictions between mechanical data-image reproduction and the embodied human interpretative labour. Each component of the imaging system of MRI introduces its own degradations, loss or, in some cases, addition of information. In this respect, the onlooker needs to be assisted by the technology and when necessary, intervene in several stages of image creation from raw data. Mallard demonstrated himself to be acutely aware of the crucial role played by the human component in the interaction with each imaging system, pointing out that

[15] Drawing upon extensive laboratory fieldwork, Alač discusses the role played by gesture and language-based interactions with the screen and other scientists in the interpretation of digital images of the brain. See Morana Alač, *Handling Digital Brains. A Laboratory Study of Multimodal Semiotic Interaction in the Age of Computers* (Massachussets: the MIT Press, 2011). On the embodied practice of molecular biology, see Myers, *Rendering Life Molecular*, (Cit. note 4).

> The last and vital link in the imaging system is, of course, the eye and the brain of the observer. The eye itself degrades the information and has its own response characteristics to be taken into account, whilst the brain has to reassemble this much degraded information presented to it and has to recognise the pattern, relate it to known normal structures and distinguish the abnormality.[16]

The hand-painted MRI image of the dead mouse became a potential diagnostic parameter as Mallard immediately understood, and at the same time, a powerful instrument of persuasion. It was with this image in his hands that Mallard persuaded stakeholders of the clinical usefulness of the MRI technology and of the need to invest resources into the development of a human body size scanner. This image became a milestone in the development of the world's first whole-body MRI scanner, an extraordinary piece of science, design, and engineering. Upon its completion in September 1978, it would be called Mark-1.[17] Mark-1 would become the first MRI scanner used to diagnose diseases in the body of a patient, becoming a major milestone in scientific achievement, and a huge step forward in the delivery of healthcare worldwide. (Fig. 2 HERE)

MRI uses a magnetic field and radio waves to create detailed images of the organs and tissues within the body. The patient lying inside the tube-shaped magnet is exposed to a strong magnetic field, which temporarily realigns hydrogen atoms in the patient's body. Radio waves cause these aligned atoms to produce very faint signals, which are then analysed by the scanner to indicate whether they came from normal or diseased tissue. After being collected by the scanner, these signals are used to create cross-sectional MRI images of the patient's tissues and organs. In the Mark-1 scanner shown in Fig. 2 the large black circles are the coils of the magnet and the copper tubes are the aerial which sends in the radiowaves and picks up the signals emitted by the atoms.

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[16] John R. Mallard, "The Radionuclide Imaging Process and Factors Influencing the Choice of an Instrument for Brain Scanning," in *Progress in Nuclear Medicine*, edited by Potchen and McCready (Karger, Basel, and University Park Press, Baltimore, 1972), 1-114, pp. 6-7.

[17] I am indebted to Professor David Lurie, Chair in Biomedical Physics and Bioengineering at the University of Aberdeen for the details related to the history of MRI in Aberdeen. Mark-1 is currently on display at the Suttie Arts Space, University of Aberdeen.

Comparable to the discovery of X-rays in 1895, there were multiple steps leading toward this scientific, technological, and diagnostic breakthrough. First, Mallard and his team were experienced in building scanners for nuclear medicine, using radioactive isotopes and gamma cameras. In 1967 they had already built a scanner for the transverse section imaging of the brain capable of giving a three-dimensional view. Mallard used the metaphor of the bacon slicing machine to explain the potentials of the transverse section imaging device:

> So far I have talked only about the taking of a single slice in a carefully chosen position. We do occasionally take two slices when it might be helpful and time permits. There is no doubt that it would be very valuable (…) to have several slices in a reasonable time. We are building a new machine which uses a gamma camera instead of a scintillation counter, to explore this. (…) Perhaps it will not be so long off before the 'human slicer' can present the living patient as a stack of individual slices, just like a non-invasive version of my father's bacon machine.[18]

For Mallard, the development of new imaging technologies had always been closely connected to problems related to image-data acquisition, display and interpretation, even before the MRI hand-painted image of the mouse and the construction of Mark-1. Second, the computer programming knowledge necessary for creating images across the body slices had been developed for nuclear medicine toward the end of the 1960s. Mallard had to face problems related to image formation and interpretation in new imaging technologies he was working on such as radioisotope scanners. For example, he highlighted that the perception of a tumor from a radioisotope scan is very complex, subjective and difficult to analyse for it depends on the observer, the display and on other factors too: "The display is looked at by the observer, whose eye and brain perceive the pattern, and relate it to the normal pattern for patients, and makes a decision about any abnormalities. These last links in the system – the perception, recognition and decision by the eye and brain is nearly always forgotten."[19] The imaging process described by Mallard in reference to radioisotope scanners is characterised by the presence of an object described by its own spectrum of spatial frequencies. The

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[18] John Mallard, "The New Bacon-Slicing Machine – a non-invasive one for humans," *Health Care Equipment and Technology*, 1978, 4, p. 9.

[19] Mallard, Radioisotope Imaging – the End of the Beginning, Separata do Arquivo de Patologia, vol. XLVI n1 Abril 1974, Lisboa, p.13.

imaging instruments detect and transmit each frequency component and the display reconstitutes the picture. The spatial response characteristics of the imaging instrument governs how faithfully the image reproduces the original object. This new model of imaging had been strongly reinforced by work in neurophysiology which has demonstrated that the human eye is very good at picking up high spatial frequencies from scans because there are nervous operators in the visual system capable of rebuilding the image from its separate frequency components.[20] The relationship between image and statistics is the other crucial factor: small statistical variations are paramount to obtain images in which details, edges and contrast are all clear and easy enough to be perceived by the observer (Fig. 3 HERE)

This picture is an interesting artist's representation of the improved diagnostic situation obtained thanks to more complex machinery, capable of providing the observer with special views, more details due to data processing and an optimisation of the display system. This picture reveals not only the technological apparatus and the patient, but also the eye, the brain and the hands of the observer, all organs working together toward making the best possible (and clinically useful) interpretation.

The third crucial condition that contributed to the success of Mark-1 was the so-called spin-warp method. Mallard and his team built upon Lauterbur to develop the spin-warp method, which proved to be crucial to point out where the signals were coming from through the patient from back to front (the addition of the coordinate Z to the X and Y). The spin-warp method allowed the creation of images from the whole body regardless of any movement (the heart's beating, the breath, the blood's pumping, the difficulty of laying still inside the scanner).[21] By 1979, Mallard

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[20] *Ibid*., p. 13. Mallard cites a neurophysiological study conducted by Maffei and Fiorentini published in the *Journal of Neurophysiology* 1972.

[21] Interview with John R Mallard, OBE FRSE, Professor of Biomedical Physics & Bioengineering, 15 November 2004, GB 0231 University of Aberdeen, Special Collections, MS 3620/1/183. On the mouse image see J.M.S. Hutchison, "Imaging by Nuclear Magnetic Resonance," in *IEE Medical Electronics Monographs 28-33, Medical Imaging*

and his team were able to get reasonably good images of themselves, although distortions were still present due to the movement of organs such as the heart. The crucial issue was not only to obtain images with this new imaging technique but also to learn what was in the images, how to read them as Mallard highlights once more:

> Could we image the liver? Could we image the kidney? We could, yes. What sort of images could we get of the brain and so on? Obviously, you've got to learn what your normal image is like before you can say, 'this is an abnormal image'. So we had to go through that stage; it took us several months.[22]

This is the reason why the Aberdeen team started to use the new spin warp imaging method that they had invented. This method could provide high quality images of the body which were by far the best in the world at that time.

After months spent experimenting the working of Mark-1 on their own bodies, Mallard and his team were ready to use Mark-1 on patients: on August the 26th 1980 the very first patient was imaged. The Mark-1 scanner was used to scan nearly 1,000 patients, until its replacement by a more powerful version in 1983. Neither the Aberdeen scanner nor the first mouse image are often mentioned in academic literature or in public engagement initiatives, despite Mark-1 being a unique historical artefact embodying the scientific principles and know-how of MRI technology. In this respect, the permanent display of the reconstructed Mark-1 imager in the Suttie Arts Space at the Aberdeen Royal Infirmary represents an excellent occasion for both scholars and the lay public to encounter not only a piece of technological equipment used to imagine the inside of the body, but a whole new world.[23] At present, Aberdeen is carrying out new work on a new MRI technology, Fast Field-Cycling MRI. A team of medical physicists lead and coordinate a EU-funded research project

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Techniques, edited by Ed. B.W. Watson (Peter Peregrinus Ltd. On behalf of Institution of Electrical Engineers, 1979), pp. 79-93.

[22] Interview with John R Mallard, OBE FRSE, Professor of Biomedical Physics & Bioengineering, 15 November 2004, GB 0231 University of Aberdeen, Special Collections, MS 3620/1/183.

[23] See http://www.ghat-art.org.uk/the-suttie-space-for-arts-2/). The display is accompanied by a documentary film directed by Rob Page on the history of Mark-1.

conducted in collaboration with research teams in six different countries. Thanks to this new MRI technology, which entails switching the scanner's magnetic field to different values while the patient is inside the scanner, further diagnostic information can be obtained that is not available from standard MRI scanners.[24]

From the time of Mark-1 onwards, computer-aided visualisation of the body and the brain for research and diagnostic purposes would improve steadily. The procedure for obtaining readable and diagnostically useful pictures became increasingly standardised and seemingly transparent, and therefore, not relevant for continued consideration. However, the epistemological role of biomedical imaging highlighted by Mallard comes again to the foreground, albeit outside the laboratory, thanks to the arts. Artists interested in working with neuroscience, its instruments, and findings look again at the scans obtained through biomedical imaging, perhaps reframing the question of what those scans stand for and what they give access to.

Moving forward from the first MRI hand-painted mouse image, the mouse brain serves today as a model for the human brain in the European flagship project Human Brain Project (HBP), which aims at creating a silicon "virtual brain" through cloud computing.[25] The study of the brain thanks to new technologies is going to be at the centre of scholarly interest and of artistic-scientific projects for a long time to come. In fact, artists and designers involved in collaborative projects with neuroscientists are currently shifting their focus away from brain scans and portraiture to living tissue – i.e. the brain cells of the mouse are being used in the installation *Silent Barrage*, a recent work by Symbiotica at the crossroad of neuroscience and art/design that shall be discussed in the second section of this article.

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[24] For further information on the new MRI technology currently under development in Aberdeen, visit: http://www.ffc-mri.org/

[25] See https://www.humanbrainproject.eu/.

The description of the human body in molecular terms was prompted by research in biomedicine and genetics after the Second World War and enabled by the advent of digital techniques of visualization and computer-assisted imaging technology, thus opening up a new era in the investigation of the body and brain interiors.[26] At present, a growing research strand in visual studies deals with material, multi-sensory contexts and practices that make use of digitalized and computerised scientific images, visualizations and models, thus combining visual studies with the field of science and technology studies (STS).[27] Within biomedical sciences, neurosciences, in particular, have attracted the attention of scholars of visual studies and STS, intrigued by the brain as a cultural, aesthetic, and scientific object.[28]

From the late 19th century to the present, a variety of techniques for imaging the interior of the body have been employed to capture the brain structure and function for research and diagnostic purposes. MRI and its functional version fMRI have been extensively applied to studies on brain anatomy and cognitive functions, contributing to the visualisation of the body composed not of anatomical organs but of the component elements of these organs, for example neurons or other types of cells or, at a much smaller scale, molecules themselves. Each MRI image, which is the result of a conversion of the analogue signal into a digital image thanks to a mathematical procedure called Fourier transform, is a 2D representation (a slice) of the3D patient's body area.[29] The transformation of the analogue signal into a digital image is possible thanks to the k-space, a grid-like structure which is the virtual space in which digitized magnetic resonance signals are stored

[26] See Drew Leder (ed.), *The Body in Medical Thought and Practice* (Dordrecht, Boston and London: Kluwer Academic Publisher, 1992).
[27] See Carusi, A., Hoel, A.S., Webmoor, T., and Woolgar, S. (eds.), *Visualization in the Age of Computerization* (New York and London: Routledge, 2015). On the importance of scientific images and visualisation for the field of visual studies, See Oliver Grau, Thomas Veigl, (eds) *Imagery in the 21st Century* (Cambridge, MA: MIT Press, 2011); William J. T. Mitchell, *Picture Theory. Essays on Verbal and Visual Representation*, (Chicago: University of Chicago Press, 1994); Gottfried Boehm, *Was ist ein Bild* (München: Fink Verlag, 1994).
[28] See, for example, Kelly A. Joyce, *Magnetic Appeal. MRI and the Myth of Transparency* (Ithaca, NY: Cornell University Press, 2008); Amit Prasad, "Making Images/Making Bodies: Visibilizing and Disciplining through Magnetic Resonance Imaging (MRI)," *Science, Technology, & Human Values*, 2005, *30:2*, pp. 291-316.
[29] Donald W. McRobbie, Elizabeth A. Moore, Martin J. Graves, *MRI from Picture to Proton* (Cambridge: Cambridge University Press, 2003).

during data acquisition. Although the *k*-space and MR image appear quite different to the eyes of the human onlooker, they contain identical information about the scanned object. The two representations may be converted to one another using the Fourier Transform.

Because MRI scans vary due to differences both in brain features (size and shape) and in slice orientation, it is useful to “normalise” a brain (that is, to translate, rotate, scale, and warp a brain) to roughly match a standard template image. The Talairach is a 3D coordinate system used to describe the location of brain structures that become “activated” in neuroimaging.[30] Before the Talairach, neuroscientists read functional images as if they were anatomical images like X-rays. Anatomy and metabolism (blood flow, oxygen consumption, et cetera) were related by means of a visual (optical) comparison between the brain scan and the paper anatomical atlas. The two representations of the brain were compared by the researcher’s eye. Mallard’s numerous remarks on the role played by the ensemble of “the eye and the brain of the observer”[31] reference this practice. This “optical” reading, as Beaulieu calls it, was superseded by a digital way of reading brain scans as a set of values in a coordinate space.[32]

Many procedures in brain and, more generally, biomedical imaging are mediated by a combined intervention of computers and humans in all stages of the visualisation pipeline, especially in the perceptual and cognitive decoding of the information.[33] These procedures highlight the absence of a direct knowledge of a condition of illness, even when the imaging technology can detect the condition of illness. In order for scans to become information and be useful for research

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[30] Jean Talairach, Pierre Tournoux, *Co-planar stereotaxic atlas of the human brain: 3-D Proportional System: An Approach to Cerebral Imaging* (New York: Thieme, 1988).
[31] Mallard, “The Radionuclide Imaging Process,” (Cit. note 16), p. 6.
[32] Anne Beaulieu, “A space for measuring mind and brain: interdisciplinarity and digital tools in the development of brain mapping and functional imaging, 1980-1990,” *Brain and Cognition*, 2002, *49:1*, pp. 13-33.
[33] Although mechanical objectivity is still present as it is clear from the discussion of the steps required to obtain the final image, brain scans are examples of the type of objectivity that Daston and Galison identify with trained judgement. Lorraine Daston, Peter Galison, *Objectivity* (New York and London: Zone Books, 2007).

and diagnostic purposes, image-data need to be well-formed, meaningful, and truthful.[34] With this goal in mind, scientists have developed techniques of normalizing and averaging data. The averaging process involved in the visualisation pipeline involves the loss of considerable information.

In spite of the highly mediated procedure for generating a brain scan, neuro-realism is grounded in the belief that fMRI enables us to capture a visual proof of brain activity despite the enormous complexity of data acquisition and image processing.[35] Dumit defines neuro-realism as the belief according to which behavioural, social, cultural, or psychological claims are seen as proven only when there is evidence of a neurological activity corresponding to them.[36] Those claims are given further plausibility when they become imaginable through the visual representation of a brain scan which is believed to be a direct representation of neural activity. For example, Dumit analysed an image taken from a longitudinal study on social immaturity. By looking at the images published as part of the study, it is evident the difference between the scatter plot of data and the final coloured image. The scatterplot data highlight that there is a large variation within each group being contrasted and much overlap in variation between groups illustrating that there is no way to know which group a subject is in – therefore, the decision to place a certain individual within a certain group is arbitrary and does not rest on hard evidence. The visually-mediated form of the neuro-realism fallacy is what Dumit calls an 'extreme image': a bright-coloured image that makes visual claims often at odds not only with the data acquired during the experiment but also with the written claims made in the scientific paper presenting the results.[37] The extreme image reduces the

[34] Floridi defines information as well formed, meaningful, and truthful data. See Luciano Floridi, *The Philosophy of Information* (Oxford: Oxford University Press, 2011).
[35] Eric Racine, Ofek Bar-Ilan, Judy Illes, "fMRI in the Public Eye," *Nature Reviews Neuroscience*, 2005, *6*, 159-164, p. 160.
[36] Dumit, "How (Not) to Do Things with Brain Images," (Cit. note 9), p. 297.
[37] *Ibid*., pp. 291-313.

scatter plot data to contrasting categories rendered as absolutely opposed to each other visually. Neuroimaging in this example is powerful at constructing “otherness”.

Colour coding was originally introduced in brain imaging as a simple way of telling at a glance how the counting-rate pattern in scans varied from point to point.[38] Nowadays, colouring brain images can drastically change the visual impact of the same data. By means of colour, brain scans risk losing their characteristic of being image-data and instead becoming extreme images. The variations in numbers are turned into qualitative fields in order to visually highlight differences: “no matter how small the actual difference in average change, the visual differences will appear stark.”[39] Although not all visualisations of the brain fall into Dumit’s category of the extreme image, his argument illustrates how difficult it is to transform data into meaningful information that can be correctly interpreted. Improving the final image from the scatter plot of data might not be a sufficient condition for overcoming the neuro-realism fallacy. Namely, the extreme image is an epistemic object that embodies a specific framework for thinking about man in the world.

To fully grasp what is at stake epistemologically when brain scans are used to nurture neuro-realism, it is useful to introduce Sellars’ distinction between the scientific and the manifest image of the man-in-the-world.[40] According to Sellars there is a clash between the so-called “manifest” and the “scientific” framework that one uses to describe and explain the position of man-in-the-world. According to the first framework, man is a being equipped with intentionality, free will, thoughts, and desires. According to the scientific one, man is an assemblage of genes, molecules, and atoms, a physical and biochemical system under the influence of environmental variables. The ambiguity

[38] John R. Mallard, “The Radionuclide Imaging Process and Factors Influencing the Choice of an Instrument for Brain Scanning,” in *Progress in Nuclear Medicine*, edited by Potchen and McCready (Karger, Basel, and University Park Press, Baltimore, 1972), 1-114, pp. 6-7.

[39] Dumit, “How (Not) to Do Things with Brain Images,” (cit. note p. 9), p. 304. Other scholars pointed out at the flaws in functional neuroimaging. See, for example, Edward Vul, Pashler Harold, “Voodoo and circularity errors,” *NeuroImage*, 2012, *62*, p. 945-948; Cornelius Borck, “How to Do Voodoo with Functional Neuroimaging,” *EspacesTemps.net*, http://www.espacestemps.net/articles/neuroimaging/.

[40] Sellars, “Philosophy and the Scientific Image of Man” (cit. note 13), pp. 1-40.

of the term image helps Sellars to highlight that the two should not be taken literally as images, but rather as two modalities in which one can imagine the way in which the world is understood and experienced in an object (image) of reflection and evaluation.[41]

The two images differ in one aspect: the manifest image does not postulate imperceptible entities and principles in order to explain perceptible things. Neurosciences, for example, by postulating ways in which cognitive and emotional processes correspond to certain entities (e.g., neuronal networks and synapses) and conveying this belief through a brain scan, slowly constructs a new framework that claims to be a description and explanation of subjectivity and its position in the world.

The extreme image does not necessarily coincide with the scientific image, rather, I argue, it is the exaggeration of the perspective put forth by either the scientific or the manifest image. One will never reach a complete description and explanation of man in the world. This is why we need to keep both views in focus in order to avoid the fallacy embodied by the extreme image. Despite what Sellars calls "the primacy of the scientific image,"[42] he argues for a "stereoscopic vision"[43] in which the descriptive and explanatory resources of the scientific image enriched by the manifest image, that is by the language of community and intentions, so that the world described by science becomes the word in which we do our living.[44] This stereoscopic vision, which remains in Sellars a goal that can be achieved only in our imagination, is the only possibility to imagine an alternative configuration for the man-in-the-world.

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[41] *Ibid*., p. 5. Sellars always uses the locution "man-in-the-world" to highlight that the image is that of the position of man in the world, not of man and of the world as two separate entities.
[42] *Ibid*., p. 32.
[43]*Ibid*., p. 19.
[44]*Ibid*., p. 5. Stereoscopic photography, interestingly, was a mean to achieve realism in science and medicine. For example, Joseph Towne, one of the most skilled makers of wax moulages in the nineteenth century, used the new technology of stereoscopic photography for constructing his three-dimensional anatomical models. On stereoscopy as an embodied form of vision in contrast with the detached and distant model of vision put forth by the camera obscura see Jonathan Crary, *Techniques of the Observer. On Vision and Modernity in the Nineteenth Century* (Cambridge and London, the MIT Press, 1990).

The stereoscopic vision enables Sellars to challenge the myth of the given, that is, the belief in self-evident, epistemic objects that guarantee knowledge of the empirical world regardless of any relationship with other concepts and contents.[45] Brain scans act as the given which grounds any cognitive and/or emotive condition that becomes real only if it can be made visible through brain imaging techniques. The myth of the given, in this case, is the belief that a specific cognitive, emotive condition is a brain property, that it is a neurophysiological condition, and in so far as it is neurological, it is real and acquires further strength when embodied in extreme images of brain structure and function.

II: Challenging the Neuro-realism Fallacy through the Arts

The category of brainhood has become a powerful visual trope in contemporary culture and mass media where the brain has become a major and fashionable icon from literature to fiction films, from politics to marketing: "Most neuroscientists are certainly modest about what they do. The media 'translations' of their results often inflate or fictionalise their significance."[46] A question like 'what defines us as humans?' is believed to undergo a profound reconsideration thanks to research on the brain undertaken by neuroscientists. One's own identity is suggested to be dependent on the biology of the brain to the point where the category of 'personhood' has been

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[45] Sellars, *Science, Perception, and Reality* (Routledge and Kegan Paul Ltd., London, 1963). For a critical reading of Sellars' myth of the given, see Willem A. deVries, Timm Triplett *Knowledge, Mind, and the Given. Reading Wilfrid Sellars's Empiricism and the Philosophy of Mind* (Indianapolis and Cambridge: Hackett Publishing, 2000).

[46] Ortega, Vidal, *Neurocultures* (cit. note 7), p. 8. *Brainhood* is one of the three key trends that Racine, Waldman, Rosenberg and Illes (2010) have identified in the media coverage of neurotechnologies. The first trend is brainhood, that is neuro-essentialism, which connotes representations of the brain as the essence of a person; the second is neuro-policy which captures the deployment of brain research to support political agendas; the third is neuro-realism which refers to the use of neuroscientific information to make phenomena seem objective or real. Eric Racine, Sarah Waldman, Jarrett Rosenberg, Judy Illes, "Contemporary neuroscience in the media," *Social Science and Medicine Journal*, 2010, *71(4)*, pp. 725-33.

substituted by 'brainhood,' which is the ontological belief that "the brain is the only part of the body we need in order to be ourselves."[47]

Scholar Fernando Vidal has suggested that brainhood is a more of a cultural figure of the modern self rather than an outcome of contemporary neuroscientific research. This perspective reverses the belief that neurosciences have transformed our concept of personhood, suggesting instead that an ideology of brainhood is the most recent epiphany of a modernist conception of the self. The modern self, Vidal argues, is now believed to be located in the brain: the belief in the coincidence between the brain and the self, was already present in the philosophical reflections around subjectivity pursued in the modern era (Descartes, Locke, Kant). This modern concept of selfhood has been challenged, first, by research in biology and, second, by accounts on the relation between subjectivity and technology. The notion of the organism as a substance whose identity is determined by some intrinsic essential principle has been challenged by recent studies on the role of symbiosis in the construction of organisms and by insights into the environment-dependent character of organisms.[48] Haraway dismisses the notions of essences to favour interfaces and communication flow: "No objects, spaces, or bodies are sacred in themselves; any component can be inter-faced with any other if the proper standard, the proper code, can be constructed for processing signals in a common language."[49] The body is turned toward multiple possible interconnections with different materialities, rather than being a substance.

ICT technologies, which are central to the creation of brain scans, have exercised an enormous impact upon the way in which identity is constructed and maintained. Floridi formulates a philosophy of personal identity based on the concept of the self as an informational structure:

[47] Vidal, *Brainhood* (cit. note 7), p. 6. Vidal quotes from Ferret by saying "Person P and person P1 are identical if they have one and the same functional brain". See Stéphane Ferret, *Le Philosophe et son scalpel: Le problème de l'identité personnelle*, (Paris: Minuit, 1993), p. 79.

[48] On the possibility of using the concept of biological individuality and an immunological perspective to challenge the notion of the self see, for example, Thomas Pradeu, *The Limits of the Self: Immunology and Biological Identity* (Oxford: Oxford University Press, 2012).

[49] Donna Haraway, *Simians, Cyborgs, Women: The Reinvention of Nature* (London: Free, 1991), p.163.

> A living organism (e.g. a spider) is cognitively present only where it is located as an embodied and embedded information-processing system. A living organism aware of its information processes (e.g. a dog dreaming) can be present within such processes (e.g. chasing dreamed rabbits) while being located elsewhere (e.g. in the house). But a self, that is, a living organism self-aware of its own information processes (e.g. you) and its own presence within them, can choose where to be. The self, and mental life in general, is located in the brain but not present in the brain. Thus, the locus of the self is the brain but the self is not present in the brain.[50]

Although Floridi still embraces a modern understanding of the self and locates mental life in the brain, he does not embrace a simplistic view of the self as *brainhood*. In fact, the passage clearly highlights how Floridi distinguishes between presence and location of the self, highlighting how the self is not present in the brain in spite of being located in the brain.

Even though challenging the neuro-fallacy may not be an intentional purpose of artists working with brain imaging and neurons, certain artistic practices enable critical engagement with the problem of the extreme image highlighted by Dumit. As will be discussed in what follows, certain art projects make brain scans and/or neuroscientific data available to be experienced by the lay public under a variety of visual and multi-media formats that might be alternative to those extreme images that appear in the media.

Needless to say, the relationship between the arts and the brain does not start with the neurosciences. One could consider Leonardo Da Vinci's early-sixteenth century-drawings of the skull, aimed at locating the soul and witnessing Da Vinci's interest in the eye, the brain and the nervous system; or Vesalius' engravings of the dissected brain in his anatomical atlas *De Humani Corporis Fabrica* (1543); or Rembrandt's painting *The anatomy lesson of Dr. Joan Deyman* (1656) representing an anatomy lesson in a group portrait. In the painting Dr Jan Deijman is portrayed performing an autopsy on a dead men's brain, with Deijman's assistant holding the top of the skull. In addition to this, any history of how the brain and the neural system have been visualized,

[50] Luciano Floridi, "The Informational Nature of Personal Identity," *Minds and Machines*, 2011, *21(4)*, 549-566, pp. 561-562.

represented and imaged before the advent of brain imaging techniques would not be exhaustive without mentioning Ramon y Cajal, the father of modern neuroscience. Cajal's exceptional ability in drawing enabled him to create accurate representations of the structure of the nervous system observed through the microscope. Rather than simply beautiful visualisations, his drawings were data in so far as they provided information, they had a hermeneutical role.[51]

In what follows, the goal is limited to offer the reader some examples of how contemporary artists have engaged with the tools, concepts, findings, methodology and visual imagery of the neurosciences for a variety of purposes, going from the attempt to tackle the concept of selfhood by means of brain imaging, to the exploration of the concept of life and creation by means of neural tissues.

It should be noted, however, that there is not attempt to give a comprehensive history of the relationship between the neurosciences and the arts. Such enterprise would not be feasible considered that contemporary neuroscience-based artistic projects are constantly evolving, with artists creating experimenting with novel techniques and neuroscientists being keen on setting up new collaborative projects. My aim is to focus on some of the key concerns and threads that have traversed the relationship of the arts and the neurosciences since the 1990s.

The artistic community is a prominent actor in the public arena where scientific discourses around the brain merge with the views of the lay public. Starting from the 1990s, in fact, artists working in a variety of media have been attracted by brain imaging as techniques of investigating and visually conveying the self. This is the case for artists such as Susan Aldworth, Suzanne Anker, Annie Cattrell, Justine Cooper, Marilene Oliver, Marta de Menezes, Sol Sneltveldt, Angela Palmer, Louise Wilson. These artists have been re-thinking portraiture in light of research developments in the neurosciences. The majority of them critically engage with the reductionism implied by the

[51] Javier DeFelipe, *Cajal's Butterflies of the Soul: Science and Art*, (Oxford: Oxford University Press, 2010).

concept of the cerebral subject both in the laboratory and in mass media, simultaneously lingering on a modern concept of selfhood. This is the case, for instance, of Aldworth's work with brain scans. The artist, an experimental print and filmmaker, explores and creatively re-assembles the different personal, medical and scientific narratives around human identity, connecting the physical brain with the notion of the self. (Fig. 4 HERE). Justine Cooper, Angela Palmer and Marilene Oliver have all used brain scans to create portraits and self-portraits after undergoing an MRI scan. Other artists such as Marc Didou, Annie Cattrell and William Kentridge represent an exception. Didou is interested in MRI as a new medium for creating sculpture challenging the cliché of the sculptor as demiurge.[52] Cattrell creates sculpture to make tangible seemingly intangible neurological experiences, such as pain and pleasure. Kentridge uses metaphorically the imagery of biomedical scans to create a cartography which blends external landscape with interior psychological landscape.

None of these artists, however, have focused on the raw data produced by biomedical imaging, preferring to pay attention to the neuroscience imagery and to brain scans. The Portuguese artist Marta de Menezes, who has a long record of art-science collaborative projects, developed a series of artworks called *Functional Portraits* (2002) in collaboration with the neuroscientist Patricia Figueiredo at the University of Oxford. Photographs of the subjects depicted are positioned at the beginning and at the end of a series of fMRI brain scans, and the orientation of the slices reproduces the photographic image (profile, face, back of the head). De Menezes created these fMRI-based portraits "in order to visualize the regions of the brain that are active while a given task is being performed. With this visual information it is possible to create functional portraits where besides the physical appearance of the subject, the function of its brain while performing a certain

[52] On Marc Didou's work with MRI, see Silvia Casini, "The Aesthetics of Magnetic Resonance Imaging: from the Scientific Laboratory to a Work of Art," *Contemporary Aesthetics. International online journal of contemporary theory, research, and application in aesthetics*, 2010, *8*.
Available at: < http://www.contempaesthetics.org/newvolume/pages/article.php?articleID=569>.

task is represented.” This discursive claim seems to be conveyed visually through a sequence of coloured brain scans that act as the extreme images discussed before. De Menezes portrays herself while drawing, the scientist Figueiredo while she plays the piano and the art historian Martin Kemp, who has devoted several studies to the examination of the relationship between art and science, while looking at a painting (*The Ambassadors* by Hans Holbein). (Fig. 5 HERE**)**

However, the attempt to frame functional brain scans as if they were portraits of the self becomes disputable. Namely, as one quickly realizes remembering that the MRI scanner would certainly not allow those types of tasks given its physical constraints, the neuroscientist was not actually playing the piano but just mimicking the gesture of playing the piano; Martin Kemp was looking at a reproduction of *The Ambassadors* and not at the original painting, and it was not clear what he was thinking of while observing the painting from inside a noisy full body MRI scanner. These functional portraits point out their own failure to convey, first of all, the fact that brain activity is not recorded in real time (therefore, what is it exactly that it is recorded and visually conveyed here? How do we distinguish signal from noise, what is left out from the original scatterplot data?), and second, the highly mediated and constructed nature of brain scans, their being a convention rather than a representation of what is going on in the brain of people while they perform certain tasks.

What De Menezes portrays is not the activity-based subjectivity of individuals involved in characteristic actions (herself painting, Kemp looking at a work of art, etc.), but rather the unavailability of those individuals to the scan eye of the machine. De Menezes strives to keep in focus both Sellars’ conceptions of man-in-the-world, the manifest and the scientific one. Both conceptions are present and simultaneously criticized as not being sufficient, if taken separately, to portray the subject as such. De Menezes is aware of the impossibility of reaching a stereoscopic vision, showing how we are forced to shift from one type of conception to the other. However, at a visual level, she reproduces the ideology of *brainhood* and the neuro-realism fallacy by remaining in the iconographic dimension of brain scans as portraits of the self.

In the installation *Weighing ...and Wanting* (1997), which is part of the so called Soho Eckstein series, the South-African artist William Kentridge embarks on a kind of psycho-topography by combining the elements of the natural and the human-built landscape with the memories, fantasies and thoughts of the main character. Kentridge's upbringing in South Africa during the violent decades when the apartheid regime crumbled, remains a constant reference point in all his artistic work. Primarily interested in drawing, his practice ranges from sculpture to animation and video installation. Kentridge has developed a particular method of animation in which he shapes single charcoal drawings into sequences on film.[53] His art has often explored the imaginary world created by sophisticated medical imaging techniques. (Fig. 6 HERE)

In *Weighing ...and Wanting* the metaphor Kentridge employs at the beginning of the film is that of the stone as a brain. The main character (Soho Eckstein) finds a stone and brings it inside his house turning it over in his hands. While Soho is inside the coil in undergoing an MRI scan, the stone appears outside again, this time etched with lines that coincide with ones drawn on brain scans to select the slices. The musical score simultaneously reproduces the thumping rhythm of the scanning. The stone is represented visually as if it were the brain of the main character inside the scanner. Slices of his brain are shown merging into memories of landscapes.

Kentridge constantly evokes, erases and draws upon these brain scans. Although Kentridge is not interested in embarking on a criticism of the neuro-realism fallacy, Sellars' framework of the manifest and the scientific image of the man can be used to explore the particular theory of subjectivity that Kentridge put forth in this work. Clearly, Kentridge does not use brain scans as if they were embodying and conveying an image of man as an ensemble of neurons, molecules and

[53] Dan Cameron, Carolyn Christov-Bakargiev and J M Coetzee, *William Kentridge*, (London: Phaidon Press, 1999).

synapses, quite the opposite. Kentridge uses brain scans as if they could expose a subject's memories, fantasies, dreams, sorrows, without constructing an image or a theory of the self ("personhood") but erasing the images he creates. Kentridge enacts the atomisation of the subject's repressed thoughts – scattered thoughts, memories and feelings. These thoughts are too fast to be conveyed in words, too imperceptible to be recorded by fMRI and mapped onto brain scans so the only way to give them a presence is by drawing them and erasing them constantly.

The artworks developed since the 1990s on neuroscience often share the use of brain scans and the re-collection of undergoing an MRI examination. However, Kentridge's gesture of erasing both brain scans and any final attempt to portray the self exposes the impossibility of lingering onto any fixed concept of selfhood and, therefore, of brainhood too given that brainhood is only the contemporary version of the modern concept of selfhood. Although still bearing upon brain scans and their imagery, Kentridge's erasing gesture succeeds at challenging the neuro-fallacy at visual level.

Since 2000 artists have become more interested in the direct use of neural cells rather than in the mediated visualisation of neural activity offered by brain scans. Bioart exemplifies this new direction undertaken by the arts. Bio-artists have been using biotechnologies to explore a variety of issues, from the modification of species with technologies to the creation of novel living entities. Bioart disrupts a certain entanglement between life and technology that often goes unquestioned both inside the laboratory and in the art field.[54] What distinguishes bioart from other types of art is first of all that bioart does not want to represent life, it wants to be life itself.[55] In bioart the subject

[54] With the concept of biopower, Foucault pointed out how technology, life, and politics became intimately intertwined in the 19th century, when life became a concept codified and disciplined through a specific apparatus. See Michel Foucault, *The History of Sexuality: Vol. 1: An Introduction*, translated by Robert Hurley (New York: Vintage, 1980).

[55] Bioart refers to the manipulation in vivo or in vitro of living cells, tissues, or organisms (or their derivatives) for creating displays that allow audiences to partake of them emotionally and cognitively. See Jens Hauser, "Observations on an Art of Growing Interest: Toward a Phenomenological Approach to Art Involving Biotechnology," in *Tactical Biopolitics - Art, Activism, and Technoscience*, edited by Beatriz da *Costa*, Kavita Philip, (Cambridge, MA: MIT Press, 2008), pp. 83-104.

and object of artistic manipulation are often life processes. The goal is to take control of and master the techno-scientific means of production in order to understand and create life processes. This is not for governing purposes, but rather for questioning the boundary between animate and inanimate matter, and for staging the material forces that govern and determine agency, life and death. In this respect, neuroscience-based bio-artworks incorporate living neurons rather than using brain scan images as the majority of artists working on neuroscience have done. Neuro-bio art does not use brain scanning or the resulting images. It uses living cells and tissues to explore what it means to be alive, the notion of a sentient and thinking being, and the ethical and political consequences that might result in having the power to manipulate these novel entities.

A number of works using neurons have been developed in the last decade, such as Marta de Menezes' *Tree of Knowledge* (2004-2005), which uses brain cells and tissue culture technologies to create living sculptures and explore the neuron as a living object and a medium. Works like *Silent Barrage* (2009) or *CellF* (2015) made by Guy Ben-Ari re-think biotechnologies using a materialist perspective. *Silent Barrage* was developed by Guy Ben-Ari in collaboration with a team of artists, designers, engineers and scientists in the laboratory SymbioticA in Australia. It investigates the nature of thoughts, decision-making, free will, and neural dysfunction. The resulting work focuses on bursts of uncontrolled activity in nerve tissue, a typical characteristic of epilepsy and Petri-dish cultured nerve cells.

In a lab there is a culture dish containing neurons harvested from embryonic rats. These neurons are connected to a number of sensors and activators which themselves are connected to the internet. In the exhibition space, which is far away from the lab, stands the robotic body of the work, an array of columns covered in paper. The petri dish functions as the neural interface of the robotic body, stimulating it via the internet. The audience provides the stimulation to which the cultured cells responds. Attached to each column is a robot that can travel up and down the column and draw on the paper. As people pass through the columns, a camera tracks their movement and relays this movement pattern over the internet back to the distant lab. Depending on the pattern of movement, individual neurons are stimulated manually. The neurons react and then organically transmit a signal to other nearby neurons in the same culture. This communication between neurons is then transmitted back to the exhibition space, each neuron mapping onto a column and the level of activity in that neuron represented by lines drawn on the paper by the robot. (Fig. 7 and 8 HERE) As people move on to investigate the more active robots, their movement triggers yet more activity in the culture dish in the distant lab, more neurons fire and robots on other columns swing into action. *Silent Barrage* cannot see visitors when they stand perfectly still, immobilised. The fact that neurons change, move and remember does not set up the patterns, presumably they learn. There is no real concept of the self so it is hard to compare them with what other artists are doing.

This immersive installation is an embodied neuronal artwork, engaging us with the concept of emergent behaviour from semi-living entities.[56] The electrical activity of nerve cells is made tangible and visceral. As one walks through the rows of columns, the feeling of physically travelling through and interacting with an active brain-body system is impossible to escape. The type of connection between the biological brain of *Silent Barrage* and the robotic body is familiar to humans: the brain processes sense data that they receive, brain and body respond, interacting through movement and mark making. This familiarity has two consequences. First, it gives the impression that the entity is a sentient form of life toward which one could develop some type of empathy. Second, it complicates our understanding of the correlations between biological/machinic components and macro activities of motion, sensory perception and interaction.

The external biological ‘brain’ of *Silent Barrage* is not primarily characterised by the property of “thinking” or of “having a consciousness,” rather, *Silent Barrage* attempts to think of

[56] On the concept of emergent behaviour in different types of systems (organisms, robots, softaware) see Chris Salter, *Alien Agency. Experimental Encounters with Art in the Making* (Cambridge and London: the MIT Press, 2015), pp. 138-141. Salter recalls the early days of cybernetics with its distinction between purposeful and purposeless behaviour.

life outside the organism, to think of the neural system as a body-brain complex, both organic and machinic, outside the boundaries of the biological brain. This novel form of life, which has a body and a culture of neural cells, does not seem to fit into any modern category of the self nor to its contemporary version, that is *brainhood*, thus becoming an epistemic object which defies any strict definition. This body-brain complex, namely, cannot be regarded as a circumscribed entity, but rather an integrated member of a machinic and organic environment characterized by dialectical exchange. In this respect, *Silent Barrage* seems to succeed in fostering a stereoscopic vision capable of maintaining both conceptions of the man-in-the-world, the scientific and the manifest one, into focus.

The challenge to the neuro-realism fallacy, therefore, is difficult to mount if artists linger on the use of brain scans as if means to convey (or fail to convey) the self. Rather, the main challenge is how to engage the wider public and neuroscientists with the challenges and opportunities of neuroscientific research and its specific visual practices, potentially influencing ethical protocols and research threads. Far from being an attempt to control and manipulate life in commodity form, bioart can thus become one of the ways in which the project of a critical neuroscience can unfold both inside and outside the laboratory.

III. Conclusions

This article has examined visual practices inside the laboratory and in the arts, highlighting a number of potential problems of reductionism in the transformation from data to images and in the visual incarnation of the neuro-realism fallacy, that is the extreme images of brain scan. As stated previously, neurosciences are not inherently reductionist, and Mallard offers an example of how neuroscientists themselves can tackle this specific fragility of their discipline. Standardization of brain imaging technology has made difficult for artists to use brain scans without reproducing also the trope of brainhood-personhood which is made visible by extreme images of brain scans or of the brain.

Returning to my initial research question: if neuro-realism is a fallacy within the neurosciences (the visual manifestation of which occurs through extreme images), are art-neuroscience collaborative projects reproducing this fallacy at visual level? Can artists us Sellars' stereoscopic view keeping together both (the scientific and the manifest) images of man-in-the-world when they engage in art-neuroscience collaboration? As I showed in this article, art practices can be distinguished between those that use brain scans as if they were portraits of the self, and those practices engaging directly with the materiality and activity of brain cells rather than with their re-mediated visual representation.

As much as there is never an innocent eye, nor a perception which is not already an interpretation, neurological data are never given, even when they assume the form of a brain scan or brain image. There has to be a theory to make the data into an image. By not engaging with the actual process of generating the scans, an art-science project like De Menezes' *Functional Portraits* fails to acknowledge the duality intrinsic to brain scans – their being both images *and* data. If the majority of neuroscience-based artworks engage with the visualization of the activity of the brain through brain scans, *Silent Barrage* operates differently, inviting onlookers to experience what it feels like to interact in real time with a semi-living entity that responds back.

In this respect, *Silent Barrage* enables us to question art practices that, in spite of engaging in a critique of neurocultures, end up reproducing those 'extreme images' that are responsible for the neuro-realism fallacy discussed. First, the focus of *Silent Barrage* is not on brain scans as representation of something (via isomorphism or resemblance) but rather on the presentation of neuronal activity incarnated in a robotic body. *Silent Barrage* questions the boundary between machines and organisms for it shows how life is material and biological as well as how matter is alive. Second, *Silent Barrage* does not seem to fall into neuro-essentialism for it interrogates not only discursively but also on a multi-sensory level the notion of a unified brain and body, making explicit how circumscribing neural activity to the brain is highly problematic. Namely, the robotic body of *Silent Barrage* plays a crucial role in the installation for triggering the interaction between the culture of brain cells and the visitor.

This is, I believe, a viable method if the broader objective is to make neuroscientific methods, findings and imagery less at the mercy of the various political and economic actors interested in exploiting the intrinsic epistemological weakness of neuroscience imagery for their own agendas.[57] Specifically, the project of a critical neuroscience here unfolds as the investigation of the material practice of neural data, with particular reference to the challenges posed by the way in which raw data are transformed into images (sometimes extreme) inside the laboratory and in art practices. Mallard's hand painted MRI image of the dead mouse was the result of an effort undertaken by humans to use their eyes and brains (to recall Mallard's expression) to develop a new technology. It pointed to one of the intrinsic fragilities of neuroscience, that is, the difficulty of visualizing, interpreting and displaying raw data.

Artists can further expose this fragility of the neurosciences, inviting scientists to take a more reflexive approach to their own visual practices and the lay public to assume a critical stance toward both the neurologisation of subjectivity and the reification of the self in extreme images. A work like *Silent Barrage* might help us to maintain a "freedom of speech" in talking about the body and the brain, inviting us to adopt a stereoscopic view when thinking about subjectivities in the world. We are thus prompted to face the dilemma of how to shape one's own technologically mediated existence in a world inhabited by multiple life forms that eschew any ready-made

[57] See Joseph Dumit, "The Fragile Unity of Neuroscience," in De Vos and Pluth, *Neuroscience and Critique* (Cit. note 12), p. 223-229. Dumit points out at the epistemological weaknesses of the neurosciences themselves, more than just at the imagery produced.

categorization.[58] Ultimately, neuroscience-based art can contribute to enhancing the contestability of the visible forms in which our selves are first imaged and then negotiated at social, cultural, and political level from within the laboratory, in mass media, and in the wider public arena.

[58] On the concept of "life forms" see Michael M. J. Fischer, *Emergent Forms of Life and the Anthropological Voice* (Durham, NC: Duke University Press, 2003).