INTERSECTING CARTOGRAPHIC IMPERATIVES. MAPMAKING PRACTISES OF A MEDICAL ARTIST IN THE WAKE OF THE COMPUTATIONAL BRAIN

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At the opening of the Humboldt Forum in Berlin, an impressive video work is displayed in the foyer: with their vivid colours, intricate patterns and dazzling animation, state-of-the-art connectomic brain images stand as a symbol for technological progress and of the hope of overcoming our human condition. This paper ethnographically describes the practice of artist, Lucius Fekonja, a medical illustrator turned neuroscientist. His specialty is the ability to draw the neural networks related to speech functions; the "zones of eloquence." Surgical planning formerly relied on atlases, on which functions were located on the outside surface of the cortex. The evolution of medical imaging techniques makes it possible to specifically map deep areas of the brain, considering the cerebral singularity of each patient—each time, a different territory to navigate. However, the force of the universalizing scheme is strong; taking the map for the territory, neuroscientists are now attempting to base their linguistic simulations on this new data. The cartographic artist is caught up in the game: he skilfully weaves different modes of scientific authority at the intersection of several cartographic imperatives. The importance conferred on the visual power these medical images prompt us to reconsider the power of maps in shaping science and its imaginaries.

The castle of Berlin has just been rebuilt in its original location — a reminder of the forgotten prestige of Prussian power. It houses the Humboldt Forum, which brings together several collections of non-European art in a vast exhibition space.[1] The museum's officials claim to be inspired by the "joy of the Humboldt brothers," the joy of travelling the world with "open eyes" and understanding it as an "entanglement between nature and culture."[2] In the majestic foyer, which leads to the restaurant and various other exhibition areas, the visitor cannot fail to notice a structure consisting of several unusually shaped screens on which colourful and spectacularly animated computer-generated images are displayed (fig. 1). This work of art heralds the opening of the Humboldt Lab, a space dedicated to interdisciplinary science exhibitions.

A set of intricate shapes float and twirl, as if suspended in the ether. They are images and maps of the 'information highways' that run through the white matter of the human brain and enable us to speak. This work presents the brain as a world in the process of being discovered, probed, and mapped out. It seems to suggest that the scientific ambitions of the Humboldt brothers

1 The opening of the Humboldt Forum and of the Berliner Schloss, designed by the architect Franco Stella, has been postponed to January 2021.

2 "*Inspiriert ist das Humboldt Forum von seinen Namensgebern Alexander und Wilhelm von Humboldt und deren Freude daran, die Welt mit offenen Augen zu bereisen und zu erkunden und sie als ein verflochtenes System von Natur und Kultur zu verstehen.*" Humboldt Forum Broschüre, 2019, p.2-3.

←↓fig. 1 Ali Hossaini, *Cosmograph*, 2019, digital modular display, dim. unknown. Lucius Fekonja & Felix Rasenhorn, *Digital Twin*, 2020, digital. Computer rendering of the *Cosmograph* display installation and of the *Digital Twin* video work in the entrance hall of the Humboldt Forum. Courtesy of Humboldt Forum, image: Ali Hossaini (final picture will be delivered in July).

have been transposed to the 21st century. An adventure reminiscent both of Alexander, who sailed around the planet, and of Wilhelm, who explored the diversity of languages as an essential revelator of the human mind. The globe, a symbol of the scientific and political appropriation of the world by Western civilization, finds itself displaced in this *mise en scène*. Here, we are referred to a new stage in the postcolonial conquest, that of inner neurobiological worlds. In his latest book, the sociologist Alain Ehrenberg describes how cognitive neuroscience has been associated with the overcoming of limits, and more generally with figures of individual action and transformation, along with the notion of cerebral plasticity.[3] In our contemporary imagination, the brain is also associated with supercomputers and deep-learning. Computers, too, now work with 'artificial neural networks,' and they are increasingly described as capable of intelligence.

Brain imaging is a specific type of technological theatre producing a fascinating entanglement of nature/culture on the stages of our computer screens, in art galleries, and here at a prominent spot of a national museum.[4] This atypical video work between neuroscience and digital sculpture is the result of the graphic research of a duo: the artist and scientist Lucius Fekonja, assisted by

3 Alain Ehrenberg, *La Mécanique des passions: Cerveau, comportement,société* (Paris: Odile Jacob, 2018).

4 See for example the work of Greg Dunn: "A Gold-Leaf Brain Lights Up With the Awesome Complexity of Neurons." *Wired*, June 25, 2016. https://www.wired.com/2016/06/your-brain-as-art/. Accessed July 6, 2020.

the designer Felix Rasenhorn. The spectators witness, as they walk by, all the facets of the contemporary brain at work: a web of interconnection and ultra-fast transmission of information in brightly coloured flashes. This piece is composed of images usually used for the planning of neurosurgical operations. The foggy black and white tomographic scans contrast with the sharpness of colourful renderings of data visualisations. The artists put them in motion by navigating in the depth of the digital material. They are choreographing the usual scrolling gesture of the imaging operators, turning it into an image dance. The tissues seem to flow onto the screens, adopting different rhythms: they adjusted to play on a hi-tech modular screen designed by a contemporary media artist, Ali Hossaini. Breaking free from the flat surface, this array of five circular LED displays is bringing volume to the pictures. As part of the dramaturgy of the Humboldt Forum, the placement of this contemporary art/science piece, at the heart of the former residence of the lords of Prussia, hints at the continuity of dominance of man on the world. "Where military power was concentrated, culture and research are now in the forefront," tells the text of the website of the institution as a voice-over on these images, reminding us unintentionally that culture and research are means of power in outer and inner worlds — and that artists have an important role to play in the performative staging of these campaigns.[5]

In this paper, I will review a case of entanglement between medical practice and neuroscience. This showcase of images and maps of the human neural central system is exemplary of the multiple regimes of the cartographic practice and of the temptations of the map maker. It demonstrates how a cartographic picture can bring a figure of speech one step closer to the status of scientific truth: in this case, the metaphor of the brain as computer. Various scientific epistemologies coexist in this practice, carrying different "epistemic values" that intersect and overlap.[6] A practitioner of "truth from nature", Fekonja contributes to the constitution of visually compelling "ideal" images in order to illustrate medical books and articles; he also abides by "mechanical objectivity", since neuroimaging obtained by MRI is commonly regarded as photographs of the brain.[7] Moreover, he participates in the mode of objectivity associated with "trained judgement." His dissertation is a tutorial that precisely aims at teaching " […] to read, to interpret, to identify significant elements of the quagmire of artefacts and the background." [8] Finally, to establish the authority of his images, Fekonja borrows the "structural objectivity" of computational neuroscience. Thriving in this ambivalence, his cartographic work is exhibited as a work of art *and* as an example of scientific excellence. The cartographer is caught in the game as a medical tool; maps of the brain help saving lives; a symbol of knowledge, they add up to the belief that human beings are independent and rational entities, standing above other types of beings and other types of neurologies,

5 "*Wo sich einem herrschenden Vorurteil zufolge früher die militärische Macht allein konzentrierte, steht jetzt Kultur und Forschung an erster Stelle; wo früher römische Herrschaftsarchitektur dominierte, finden sich nun erneut auch die außereuropäischen Kulturen*." Accessed May 20, 2020, https://www.smb.museum/museen-einrichtungen/humboldt-forum/home/.

6 Daston and Galison, *Objectivity*.

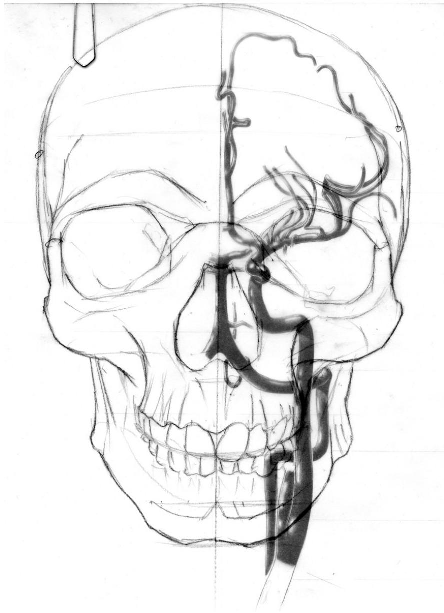
7 Daston and Galison; Burri, "Visual Power in Action."

8 Daston and Galison, *Objectivity*, 238.

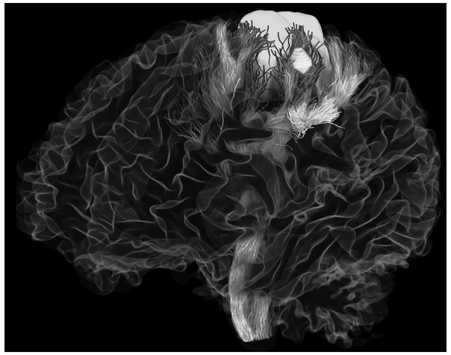
and readily augmentable to fulfil their anthropocentric dreams.

A Cartographer of White Matter

Now a brain matter cartographer, Lucius Fekonja had an atypical start to his career. He began his university career with medical illustration, training in Lucerne and Zurich. This curriculum includes classical painting, drawing, graphic design, and 3D visualization. Attracted by the neuro-medical field, he then began a doctorate in medical sciences at Charité University Hospital, working in parallel as an illustrator for the chef of the department of neurosurgery (fig. 2). From time to time, I spend a moment with him at the office, in the small room shared by our interdisciplinary research team on the fifteenth floor. As a postdoctoral associate researcher in the Cluster of Excellence "Matters of Activity" (Humboldt Universität zu Berlin), I am currently doing fieldwork at the University Hospital of Charité on digital imaging crafts in neurosurgical planning. In recent years, Fekonja's research has improved the practice of mapping neural networks, particularly those dedicated to language functions, the so-called 'eloquent zones.' This is a relatively new field of brain imaging, called 'tractography,' a non-invasive technique by which a complex algorithm can sketch, for a specific patient, a sort of road map of the inside of the head (fig. 3).



↑fig. 2 Lucius Fekonja, untitled, 2019, graphite pencil on paper. Published on "Matters of Activity" Accessed June 3, 2020. https://www.matters-of-activity.de/en/.



↑fig. 3 Lucius Fekonja, untitled, 2019, digital. Published on "Matters of Activity" Accessed June 3, 2020. https://www.matters-of-activity.de/en/.

According to the expression that Fekonja often uses to give a quick introduction to his work, the 'white matter' is an interlacing of cables that connect the computers located in the famous 'grey matter.' There are 86 billion neurons in the brain, a number that is often quoted in popular science literature and still baffles our imaginations. A proportion of the neurons are oriented in 'fibre bundles' that connect distant regions of the brain. Based on a series of cases showing consequences of injuries in these deep regions,

researchers have discovered that these networks are more decisive than grey matter areas for the proper functioning of the brain, and in particular for advanced functions such as language.[9] The associationist paradigm, which is the mainstream in neuroscience today, considers that these large-scale networks are essential for functions such as language, reasoning, and the memory of emotions.[10] Their epicentres constitute "relays or integration centres, hubs, nexuses, sluices for convergence, divergence, feedback loops, feed-forward connections, and transition points from serial to parallel processing."[11]

In the case of tumours or other slowly progressing conditions, the brain can reorganize the functions by moving these functional 'hubs' elsewhere, following the connections already established with other regions of the brain. The brain's proven ability to reorganize itself allows neurosurgeons to dig into certain parts of the tissue without fear of affecting the patient's life. Other procedures are much more difficult and riskier — especially when tumours reach the 'eloquence zones,' the areas of white matter that are critical to speech functions. Patients from all over the world are sent to the virtuoso specialists at the Charité University Hospital. Fekonja's concrete mission is first to prepare the neurosurgeons' approach to these dangerous areas, and secondly, to pass on and disseminate this mapping know-how within the profession. For both of these aims, he relies on various ways of establishing scientific certainty, reaching outside of disciplinary boundaries if necessary; the power of his pictures lies beyond aesthetics. In a quasi-religious manner, knowledge about the working of our souls is intertwined with top of the art 3D imaging technologies, life or death skills of the surgeons, and neurocomputational modelling. However, these enormous powers, which clearly animate him at a 'subjective' level, can be discarded by their author as by-product of a concrete and result-driven activity; that of finding out the optimal cut in the brain to save a patient. Moreover, this medical 'cartographic imperative' plays together with another current 'cartographic imperative' in neurosciences, an epistemic fashion that makes the mapping of cognitive functions tantamount to an explanation of them.[12] Before moving on to neuroscience, let's focus first on the medical aspect of the cartographic practice.

Navigation with Reduced Visibility in Perilous Areas

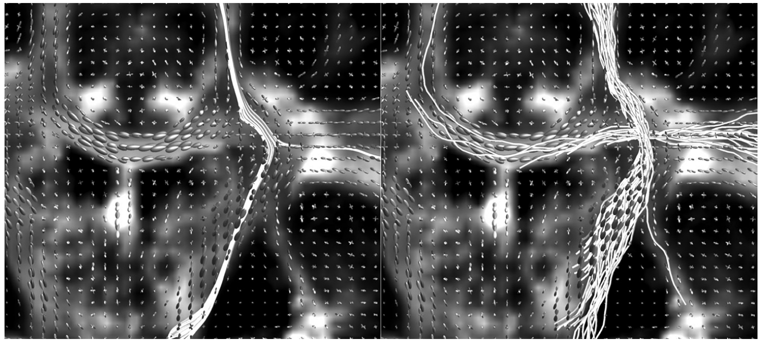
Neurosurgical planning is a navigational activity based on topological data specific to each patient. The aim is to mark out the 'route' that the surgeon will travel through the material using his instruments. The data nowadays

9 For a synthetic review, see Hugues Duffau, "White Matter Pathways in the Human," in *Neurobiology of Language*, ed. Gregory Hickok and Steven L. Small (San Diego: Academic Press, 2016), 129–37, https://doi.org/10.1016/B978-0-12-407794-2.00011-0.

10 Marco Catani et al., "Beyond Cortical Localization in Clinico-Anatomical Correlation," *Cortex* 48, no. 10 (November 2012): 1262–87, https://doi.org/10.1016/j.cortex.2012.07.001. ; M.-Marsel Mesulam, "Behavioural Neuroanatomy: Large-Scale Networks, Association Cortex, Frontal Syndromes, the Limbic System, and the Hemispheric Specializations.," in *Principles of Behavioral and Cognitive Neurology*, ed. M.-Marsel Mesulam (Oxford University Press, 2000).

11 Marco Catani and Marsel Mesulam, "The Arcuate Fasciculus and the Disconnection Theme in Language and Aphasia: History and Current State," *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior* 44, no. 8 (September 2008): 953, https://doi.org/10.1016/j.cortex.2008.04.002; Marco Catani and Marsel Mesulam, "What Is a Disconnection Syndrome?," *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior* 44, no. 8 (September 2008): 911–13, https://doi.org/10.1016/j.cortex.2008.05.001.

12 David Poeppel, "The Cartographic Imperative: Confusing Localization and Explanation in Human Brain Mapping," in *Ikonographie Des Gehirns* (Berlin, Boston: De Gruyter, 2017), 19–29, https://doi.org/10.1515/9783110548778.



←fig. 4 Lucius Fekonja, *Deterministic and probabilistic tractography in comparison*, in press, digital.

comes mainly from magnetic resonance imaging (MRI). These non-invasive techniques systematically 'slice' the body into a series of images. In the case of a tumour, the assistant surgeon, using dedicated software, traces the path to access a surgical region of interest. The aim of this exploration is to anticipate the hazards, with the exact layout of the blood vessels, as well as many other factors known and identified by practitioners in medical atlases. Information on the path of the fibre bundles associated with certain critical functions can be decisive to make the right cut. The main challenge is that these 'paths' inside the white matter are totally invisible to the surgeon during the operation, and they vary depending on the individual anatomy and pathology. Different techniques are used to trace them before and during the operation to prepare for the approach and the resection phase, thus increasing the chances of success of the operation. Functional tractography, which is integrated into the pre-operative planning, has already become an established practice among the Charité's clinicians. However, it has been slow to gain wider acceptance as a standard method. Fekonja's main contribution to this field of study is the development of an easily reproducible and reliable mapping method of the speech functions in the white matter.

Through which means and using which criteria does Fekonja influence what will appear on the screen? This question can only be answered by describing the labour involved in data processing.[13] Without being able to go into details here, let us concentrate for a moment on one of these stages, the choice of the statistical processing method. In order to determine the path of the fibre bundles, the technicians use data from the detection of the diffusion of water molecules by a special protocol (dMRI). Inside each voxel, the scanner measures the direction of diffusion of these particles and the computer performs a calculation to determine in which direction the material is oriented within each of these tiny spaces (a 'diffusion tensor'). The operator then aggregates this data with a statistical tool to determine the most likely paths taken by certain 'information highways' within the white matter. As can be seen in figure 4, different analysis processes produce very different visual results. Fekonja explains that he chose

13 See for an explanation of the methodological framework the seminal article of S. L. Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (November 1, 1999): 377–91, https://doi.org/10.1177/00027649921955326.

the method that offers the possibility of showing the path of intersecting fibres within a single voxel, allowing for a larger number of bundles to be visualized (image on the right). The visual results certainly give the satisfying feeling that these paths (in white on the picture) are drawn more completely. It is then necessary to adjust the sensitivity of the statistical tool so that the fibres do not radiate in all directions. These interventions of the cartographer are conducted with several factors in mind, partly related to the economy of data visualisation, partly to aesthetics: the standards of the profession, an imagined anatomy, readability, and sheer visual appeal.[14]

Digital Brains: Neuronic Cables and Computers

The visual power of images is an important means to establish this new practice in the routine of the neurosurgeons. However, it is not the only one that Fekonja and his team are putting into use. Scientific authority can be strengthened through the interplay with other disciplines and other epistemological practices and types of objectivity. In a tactical move, the Image Guidance Lab is increasingly collaborating with colleagues in computational neurolinguistics.[15] In opposite to approaches driven by the visual, mathematical modelling is related to the epistemic values of "structural objectivity", which the historians of science Lorraine Daston and Peter Galison describe as an "objectivity without images."[16]

The simultaneous emergence of 'brain as computer' metaphors, discoveries of 'neural networks' in the brains of living patients, and the appearance of neurocomputational simulations is not accidental. The construction of the brain as a calculator and the calculator as a brain has a long history. In his investigative work on neuroscience, the anthropologist Joseph Dumit chronicles some of the pioneering contributions in these fields and tells how 'brain circuits' got to where they are today. Dumit identifies the experimental epistemology of the cyberneticians Mc Culloch and Pitt, the "original work defining the field of neural nets", as a turning point dating back to the 1940s.[17] Ironically, the computer machine was initially considered by researchers as profoundly irrational, because of its basic errors of judgement and because it tends to enter into obsessive and pathological looping behaviour. Yet, as a result of the graphic innovations of these researchers and their successful efforts in developing the models needed to understand the specific logic of these machines, they have become the dominant way to represent healthy brain function. Thus, the presence of these circuits is a

14 For thoroughly documented account of the importance given by practitioners to f the visual power of brain images, see Regula Valérie Burri, "Visual Power in Action: Digital Images and the Shaping of Medical Practices," *Science as Culture* 22, no. 3 (September 2013): 367–87, https://doi.org/10.1080/09505431.2013.768223.

15 These epistemic strategies are facilitated by Clusters of Excellence such as the one that is partly funding the IGL ("Matters of Activity", DFG), as well as my own fieldwork. It should be noted that if self-reflexivity brought by humanities is positively perceived in these contexts, as a warrant for societal purposefulness of the research, they are more difficult to integrate to the tactical disciplinary crossovers which are considered as productive by the scientists. See in particular Paul Rabinow and Gaymon Bennett, *Designing Human Practices: An Experiment with Synthetic Biology* (Chicago ; London: The University of Chicago Press, 2012).

16 Lorraine Daston and Peter Galison, *Objectivity* (New York; Cambridge, Mass.: Zone Books ; Distributed by the MIT Press, 2007), chap. 5.

17 Joseph Dumit, "Plastic Diagrams: Circuits in the Brain and How They Got There," in *Plasticity and Pathology: On the Formation of the Neural Subject*, ed. David Bates and Nima Bassiri, 2016, 224–25, https://escholarship.org/uc/item/793954xw see also; Joseph Dumit, *Picturing Personhood: Brain Scans and Biomedical Identity* (Princeton, NJ: Princeton University Press, 2004); David Bates, "Automaticity, Plasticity, and the Deviant Origins of Artificial Intelligence," in *Plasticity and Pathology: On the Formation of the Neural Subject*, ed. David Bates and Nima Bassiri (Fordham University Press, 2016), 194–218, https://muse.jhu.edu/book/51915.

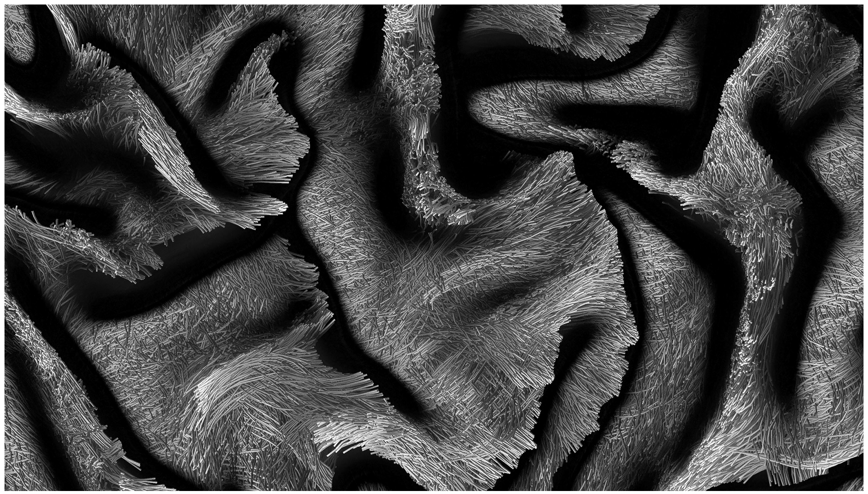
theoretical presupposition on which the simulation tools of neuroscientists are based nowadays. Their current approach focuses on modelling the logical and symbolic abilities of human beings, gradually increasing the complexity of their simulations. Thus, the model used for the simulations by Rosario Tomasello, who collaborates in new project with Lucius Fekonja, is presented as the 'state of the art' in the field of 'brain-inspired' neural networks.[18] Tomasello is integrating the newly available data regarding the life and death of neurons and synapses in the logical constraints of his simulation. The aim of these models is to bring together "everything we know about the brain" — in any case a large body of knowledge is synthesized in them — in order to understand the universal functioning of certain brain mechanisms, in particular those relating to language and symbol operations.

Within the past decade, behemoth projects have been started with the goal of mapping all brain connections at the level of the single neuron. Researchers in this field consider that mapping the connections at the neuron level would make it possible to understand the workings of individual minds. As one of the authors of a blog of the NIH related to the Human Connectome Project puts it; "these days some of the world's top neuroscientists might say: 'You are your connectome'." There are various approaches; some start with simpler organisms, such as fruit flies, others by taking a very small part of a human brain.[19] A community of researchers is betting

18 Rosario Tomasello et al., "Neurophysiological Evidence for Rapid Processing of Verbal and Gestural Information in Understanding Communicative Actions," *Scientific Reports* 9, no. 1 (December 2019), https://doi.org/10.1038/s41598-019-52158-w; Rosario Tomasello et al., "Visual Cortex Recruitment during Language Processing in Blind Individuals Is Explained by Hebbian Learning," *Scientific Reports* 9, no. 1 (December 2019), https://doi.org/10.1038/s41598-019-39864-1.

19 C. Shan Xu et al., "A Connectome of the Adult Drosophila Central Brain," *BioRxiv*, January 21, 2020, 2020.01.21.911859, https://doi.org/10.1101/2020.01.21.911859.; and see the work of Jeff Lichtman; iBiology. *Jeff Lichtman (Harvard) Part 3: Brain Connectomics?* Accessed June 26, 2019. https://www.youtube.com/watch?v=2QVy0n_rdBl.

↓fig. 5 Lucius Fekonja, untitled, 2019, digital. Published on the website of the Cluster of Excellence "Matters of Activity", accessed June 3, 2020. Representation of white matter, in the cannon of connectomics.



on tractography.[20] Their results focus on the living human brain, cross-referencing behavioural data with topological data, and they focus mostly on the global structures, enabling the production of atlases, such as the ones mostly used by Fekonja.[21]

The encounter between connectomics and computational neurolinguistics, because they are based on the same theoretical presuppositions, seems inevitable. The arrival of these data sets from tractography gives Fekonja and Tomasello the possibilities to add new parameters to computational neuroscience simulations — new structure, new clues about the actual connections between regions. Rosario Tomasello recently presented to the team a finely parcelled 3D map of the cortex on which the brain is divided into 400 areas. The transaction works both ways; neuroscientists can now imitate brain structures in an increasingly precise and convincing way, relying on the matching operations undertaken by white matter cartographers, on their clinically proven results, and on the persuasive power of their sophisticated images (fig. 5).[21] In turn, the cartographer gives to his images a new regime of scientific authority conferred by neuro-computational simulation, and with it, the authority of mathematical proof, the ultimate level of universal knowledge within the modern scientific tradition.

Cartographic imperatives and the neurological imperium

In a founding text of the anthropology of science (and cartography), Bruno Latour tells an anecdote about La Pérouse, a contemporary explorer of the Humboldt brothers.[23] The navigator requests the natives to draw for him, in the sand, a map of the island on which they stand. The drawing, which has the authority of local knowledge and has become a sketch in the cartographer's notebook, takes on a completely different status as it enters a different regime of knowledge. As an "immutable mobile", it will be compared and integrated with many others in order to build a new certainty. At the intersection of several 'cartographic imperatives,' the map then becomes an object of geopolitics and colonization.

In this paper, I show how a specific mapping practice, not yet fully established, grows from local concerns related to surgical care and swarms in different directions, shifting to other regimes of knowledge under the powerful drive of intersecting imperatives. Tactically intertwining these modes, the neuroscience artist researchers can be related, indeed, to the model of the 'universal' academic achievement of the early moderns, and their forceful renewing of entanglements of nature and culture. Their position is exhilarating, as the results are tested as medically effective, confirmed by peers in

20 Klaus H. Maier-Hein et al., "The Challenge of Mapping the Human Connectome Based on Diffusion Tractography," *Nature Communications* 8 (November 7, 2017), https://doi.org/10.1038/s41467-017-01285-x.

21 Catani et al., "Beyond Cortical Localization in Clinico-Anatomical Correlation."

22 As Anne Beaulieu noted, neuroscientists prefer digital data to images, but they are not insensitive to the visual power of images when it comes to convincing their audience of their findings — even if the images don't confirm their claims! If the computer-generated drawing is shown in the presentation, it is actually the matrix of numerical data that is more important than the map Anne Beaulieu, "Images Are Not the (Only) Truth: Brain Mapping, Visual Knowledge, and Iconoclasm:," *Science, Technology, & Human Values* 27, no. 1 (2002): 53–86, https://doi.org/10.1177/016224390202700103.

23 Bruno Latour, "Visualisation and Cognition:Thinking with Eyes and Hands," in *Knowledge and Society Studies in the Sociology of Culture Past and Present*, ed. H. Kuklick, vol. 6 (Jai Press, 1986), 1–2.

the fast-paced publishing circuit of natural sciences, met with success at grant applications, and showcased as works of art. In the name of the advancement of medical care, they open a new territory to the modernist conquest: the neurobiological self. This position comes with a responsibility: There are dangers and opportunities to such powerful entanglement as brain science.[24] As the Canadian philosopher Erin Manning puts it: "it is urgent to turn away from the central tenet of neurotypicality, the wide-ranging belief that there is an independence of thought and being attributable above all to the human, a better-than-ness accorded to our neurology."[25] The worlding activities of Fekonja and his colleagues are followed closely by financing bodies in research and increasingly in the industry, shaping a new instrumentarium and new disciplinarian dispositives that will be passed on to our children. Collaborative work between natural scientists and the humanities should hint to the part we could play together in mapping our future as earthlings, rather than as brainlings.

24
An inspiring case was made by anthropologists in the field of synthetic biology, see Rabinow and Bennett, *Designing Human Practices*.

25
Erin Manning, *The Minor Gesture*, Thought in the Act (Durham London: Duke University Press, 2016), 3.

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