Neural Media:

Ascribing, Animating, and Artificializing Intelligence

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Théo Lepage-Richer, whose work appeared in journals such as *Computational Culture* and *Big Data & Society*, graduated from McGill University in 2013 with a B.A. with distinction in Cultural and Communication Studies. He also holds an M.A. in Culture Studies from Goldsmiths, University of London (2014), which was also awarded with distinction. In 2017, Théo joined the Department of Modern Culture and Media at Brown University, where he benefitted from doctoral awards from the Social Sciences and Humanities Research Council (SSHRC) and the Fonds de recherche du Québec—Société & Culture. In 2019, he completed a Graduate Certificate in Science and Technology Studies before meeting all the necessary requirements to be awarded an M.A. in Modern Culture and Media in 2020. Throughout his PhD, Théo held visiting positions at Charles University (Prague, Czech Republic), Simon Fraser University (Burnaby, BC), Concordia University (Montréal, QC), and the Institut national de la recherche scientifique (Québec City, QC), while also being appointed as an external advisor for the Socially Responsible Computing program at Brown's Department of Computer Science. Following his graduation, he will join the Institute of Communication, Culture, Information and Technology at the University of Toronto as a SSHRC Postdoctoral Fellow.

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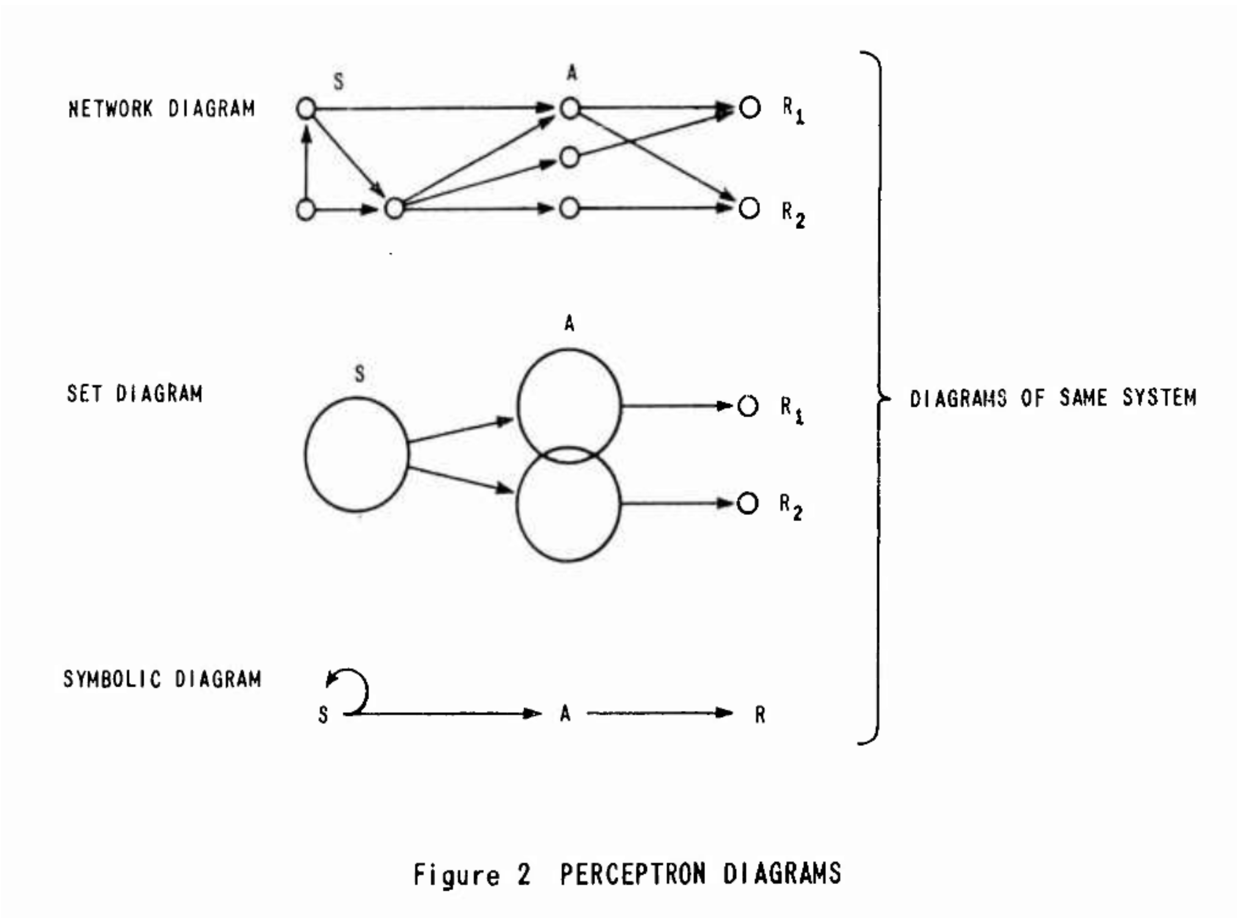

Figure 1. Three representations of the same single-layer, perceptron style neural network. Frank Rosenblatt, *Principles of Neurodynamics: Perceptrons and the Theory of Brain Mechanisms*. Buffalo, NY: Cornell Aeronautical Laboratory, 1961. p. 86.

"For a long time, the human was something else altogether; it is not so long ago that it became a machine—a calculating one no less."[1] However contemporary this statement might sound, it wasn't formulated by some famous media philosopher or posthumanist scholar. Instead, it is by French sociologist Marcel Mauss[2] who, a hundred years ago, commented on the growing influence of a new conception of intelligence as the product of intricate webs of calculating units called "réseaux neuronaux"[3] or neural networks. When introduced by Spanish histologist Santiago Ramón y Cajal at the end of the 19th century, this model involved reconceiving of the brain as constituted of discrete nerve cells intricately connected to one another. Away from previous neuroanatomical models, which pictured the brain as made of continuous nervous fibres, it provided a new fundamental structure to not only locate and measure intelligence, but also anchor within neurophysiology alleged differences in intellectual potential. Formulated at a time when advances in histology showed that the brain of all humans was essentially identical at the microscopic level, neural networks constituted a new albeit yet-to-be-seen structure reinscribing within the brain the assumed racial divide differentiating Europeans from the populations native to their colonies. Relentlessly slicing, staining, scrutinizing, and drawing brain tissues, Ramón y Cajal developed his model through the experimental manipulation of cadavers, which he used as a proxy for the racialized bodies whose perceived difference he aimed to provide a biological basis to. Decades before neural networks would be embodied by electric circuits, computers, and learning machines, it was thus a specific type of body—namely, that of cadavers—that provided both the inspiration and the vehicle for new ideas about intelligence's structural basis and uneven

[1] All quotes from texts in French, Spanish, and Italian are free translations by the author except when it is their English translation that is directly cited .
[2] Marcel Mauss, "Essai Sur Le Don: Formes et Raisons de l'échange Dans Les Sociétés Archaïques," *L'Année Sociologique* 1 (1923): 176–77.
[3] Santiago Ramón y Cajal, "Structure et Connexions Des Neurones," *Nordiskt Medicinskt Arkiv* 1, no. 2 (1907): 19.

distribution, a reconceptualization that was as much neurophysiological as sociological if not altogether racially inclined.

In this dissertation, I take as my case studies three such episodes when the notion of neural networks was not only deployed as a solution to the problem of intelligence, but also framed as such by being directly inscribed onto bodies that were recognized as the bearers of various forms of human difference. While now known as a biologically inspired approach to artificial intelligence relying on probabilistically weighted neuron-like units to recognize patterns in data, neural networks were first introduced as a neuroanatomical approach to racial difference before being recast into a new way to both diagnose and treat mental illness based on neurophysiology alone. Traversing fields and time periods as varied as late 19th-century histology, wartime psychiatry, and late 20th-century computer science, neural networks indexed not only changes in the articulation of intelligence, but also the development of new means to locate and attribute the latter across humans and machines alike. Despite their assumed coherence through time, as well as status as an abstract model applicable to both the living and the artificial, neural networks have been materialized through practices as varied as silver staining and colonial hygiene policies, brain lacerations and various forms of shock therapy, and finally organizational reforms and the programming of software simulated neurons. If anything, what unifies these iterations is a broader organizational ethos that systematically involved experimenting on, managing, and disciplining certain bodies, while devaluing the practical, local, and contextual knowledge they held. Turning Lucy Suchman's famous invitation to attend to how the prospect of "machines-as-agents"[4] is produced on its head, this project then proposes to examine three sites where the prospect of

[4] Lucy Suchman, *Plans and Situated Actions: The Problem of Human Machine Interaction* (Cambridge, UK: Cambridge University Press, 1987), 2.

agents-as-machines—i.e., that agency and intelligence necessarily involve structural, mechanically reproducible qualities—was first articulated and later sustained.

At its core, this project makes the following argument: far from abstracting the brain, the mind, and even human sociability into a unified theory of intelligence, neural networks were deployed to bring all these things under new forms of social control, which were themselves deemed more rigorous, rational, and altogether intelligent. In each of their main iterations, neural networks were introduced as a response to growing anxieties about the biological basis—or its lack, rather—of racial difference, mental illness, and intelligence by introducing new fundamental structures that embodied, and thus re-stabilized, these concepts. In the face of colonial decline, deinstitutionalization, and bureaucratic mismanagement, which each brought into question the more centralized approach of the institutions in which this model (re-)emerged, neural networks not only reduced complex phenomena to locatable structures, but also rendered the latter both legible and available as proxies for the control and management of the former. As such, neural networks offered technoscientific solutions to what were essentially social problems and bridged the gap between both registers by being projected, when not directly inscribed, onto the bodies deemed most problematic. From cadavers and psychiatric patients to low-wage workers, neural networks singled out certain bodies as vehicles for the promotion of the new ideas about organization, communication, and control they embodied at the same time as they made them the privileged targets of a whole range of experimental, clinical, and managerial interventions. By providing a biological basis to human difference, a neurophysiological explanation to mental illness, and a computational rationale to organizational reforms, neural networks operated not so much as a discrete model but rather as a mediating figure[5], which, in conjunction with the rise of colonial hygiene, somatic approaches to mental illness, and technocratic models of public management, mediated who or what was recognized as the bearer of intelligence—and, more importantly, who wasn't.

This type of biopolitical organization of intellectual potential, which traverses neural networks' various iterations, goes beyond current conversations around so-called control societies and the machines that best capture their sociopolitical logic. In the wake of Gilles Deleuze's "Postscript on Control Societies," which posits that "societies of control operate with […] computers"[6], information technologies like neural networks have overwhelmingly come to be understood as both the drivers and symptoms of a broader epochal break defined by the more distributed forms of control these technologies enable[7]. But what neural networks' historical trajectory highlights is the gradual recognition of such a distributed model as having a biological origin, insofar as it came to be seen as being constitutive of the structure of the brain itself. Once understood as flexible albeit highly stratified network of specialized units, the brain became a privileged model for the management of populations as varied as colonized populations, psychiatric populations, and government workforces. And yet, this recognition is key as there is nothing deterministic in the way neural networks are represented, conceived of, or even made to invoke the neural domain. In the field of computer science, for instance, where neural networks are now seen as the most promising pathway to human-level intelligence, there was no consensus vis-à-vis how to represent neural networks up until the 1970s (see Figure 1). That neural networks

[5] I use this term with Donna Haraway's own use of it in mind, namely, as a "strongly visualizable form" bridging the realm of the material with that of the semiotic. See Donna Haraway, *Crystals, Fabrics, and Fields: Metaphors of Organicism in Twentieth-Century Developmental Biology* (New Haven, CT: Yale University Press, 1976), 41.

[6] Gilles Deleuze, "Postscript on the Societies of Control," *October* 59 (1992): 6.

[7] e.g., Seb Franklin, *Control: Digitality as Cultural Logic* (Cambridge, MA: The MIT Press, 2015); Alexander Galloway, *Protocol: How Control Exists after Decentralization* (Cambridge, MA: The MIT Press, 2006); David Golumbia, *The Cultural Logic of Computation* (Cambridge, MA: Harvard University Press, 2009).

have come to stand as a logico-mathematical albeit highly hierarchical abstraction of the brain's fundamental structure is but the product of sustained efforts to both reduce all brain functions to the interactions among tightly interconnected units and recast the whole of human biology, psychology, and sociability onto a similar model. As such, what neural networks highlight is how the very notion of neurality is itself a highly performative construct, which promotes organizational principles such as atomization, interdependence, and mediation in the spheres in which it is adopted while framing them as biologically given.

The three main iterations of neural networks that this project attends to, while questioning the teleological narrative that frames them as part of the same trajectory, are the following: the introduction of biological neural networks by Spanish histologist Santiago Ramón y Cajal[8], the invention of artificial neural networks by American psychiatrist Warren McCulloch[9], and the software implementation of deep neural networks by British-Canadian computer scientist Geoffrey Hinton[10]. I selected these episodes for how they have become signs of the gradual yet steady convergence of human and machine intelligence. Not only are these three moments regularly referred to as the main milestones in the history of AI by computer scientists[11], popular commentators[12], and historians[13] alike, but even their protagonists—Ramón y Cajal, McCulloch, and Hinton—conceived of themselves as part of the same trajectory. Whereas McCulloch

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[8] Santiago Ramón y Cajal, "Estructura de Los Centros Nerviosos de Las Aves," *Revista Trimestral de Histología Normal y Patológica* 1 (1888): 1–10.
[9] Warren McCulloch and Walter Pitts, "A Logical Calculus of the Ideas Immanent in Nervous Activity," *Bulletin of Mathematical Biophysics* 5 (1943): 115–33.
[10] Geoffrey Hinton, James McClelland, and David Rumelhart, "Distributed Representations," in *Parallel Distributed Processing: Explorations in the Microstructure of Cognition, Volume 1* (Cambridge, MA: The MIT Press, 1986), 77–109.
[11] e.g., Ian Goodfellow, Yoshua Bengio, and Aaron Courville, *Deep Learning* (Cambridge, MA: The MIT Press, 2016).
[12] e.g., Ray Kurzweil, "Foreword to the Third Edition," in *The Computer and the Brain* (New Haven, CT: Yale University Press, 2012), xi–xxxii.
[13] e.g., George Nagy, "Neural Networks - Then and Now," *IEEE Transactions on Neural Networks* 2, no. 2 (1991): 316–18.

described his model as a mathematical interpretation of Ramón y Cajal's previous efforts to "quantize living things"[14], Hinton for his part attributed to McCulloch the original insight that "the nervous system computes"[15]. In the context of a model that has systematically been defined in opposition to other fields and approaches such as reticular theory, psychoanalysis, and symbolic AI, this narrative has been especially key in not only endowing neural networks with a stability they otherwise lack, but also justifying the instability introduced by their application to an ever-growing range of objects and phenomena, from the brain and the mind all the way to intelligence itself.

To explore this dialectical relationship between stability and instability in the history of neural networks, I draw on Hans-Jörg Rheinberger's work on experimental systems. Defined by Rheinberger as "vehicles for materializing questions"[16], experimental systems consist in the fundamental unit of experimentation, where the technical, epistemic, social, and institutional components of laboratory work converge in the form of situated objects[17]. Since its introduction, this concept has been appropriated by many media studies scholars[18] to theorize how various media technologies render new situations, settings, and cultural milieus available to experimentation—a move that provides deeper critical purchase on neural networks' own mobilization of bodies of all kinds as objects of histological, clinical, and ultimately computational manipulation. In Ramón y Cajal's case, it was the cadaver that constituted such a vehicle, by providing the necessary

[14] Warren McCulloch and John Pfeiffer, "Of Digital Computers Called Brains," *The Scientific Monthly* 69, no. 6 (1949): 368.
[15] Geoffrey Hinton and James Anderson, "Introduction to the Updated Edition," in *Parallel Models of Associative Memory: Updated Edition*, ed. Geoffrey Hinton and James Anderson (Hillsdale, NJ: Lawrence Erlbaum Associates, 1989), 9.
[16] Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford, CA: Stanford University Press, 1997), 28.
[17] Rheinberger, 238.
[18] e.g., Patrick Jagoda, *Experimental Games: Critique, Play, and Design in the Age of Gamification* (Chicago, IL: University of Chicago Press, 2020); Colin Milburn, "Modifiable Futures Science Fiction at the Bench," *Isis* 101 (2010): 560–569.

materials to search for the biological basis of perceived differences in intellectual potential. In McCulloch's, it was psychiatric patients who fulfilled this role, by constituting a seemingly self-evident pathological counterexample to the normal structure and organization of the mind. In Hinton's case finally, it was the low-ranking government clerk, by being recognized as a promising candidate for the automation of certain forms of intellectual labour. More than straightforward outputs of these bodies' experimental manipulation, neural networks stood as devices mediating these bodies' availability as objects of experimental manipulation, highlighting the central role of both experimentation and embodiment in the historical development and evolution of neural networks.

Bringing these different threads together, each of this project's sections will be structured around two main lines of inquiry, with the underlying aim of identifying the phenomena that neural networks' three main iterations were designed to not so much model as bring under control. First, each chapter will begin by attending to the broader problems that neural networks' iterations were designed to address. Tellingly, none of these were essentially neurophysiological or computational in nature and it is precisely as means to recast social problems in neurophysiological or computational terms that neural networks were deployed. From there, each section will then identify the specific bodies that were selected as the human counterpart of neural networks. Tellingly again, none of these was the type of universal subject neural networks were supposed to represent. Instead, they were selected among the bodies that were deemed most problematic by my protagonists, who mobilized them as objects of experimental manipulation for the way they were seen as deviating from the principles their neural networks embodied. In each chapter, this structure will translate as follows: in my first chapter, I will relate neural networks' initial articulation to the renegotiation of the relationship between European empires and their colonies, while emphasizing how the cadaver became a privileged medium to inscribe onto human biology a highly interconnected albeit hierarchical view of human organization. In my second chapter, I will locate the invention of artificial neural networks within postwar medical institutions' attempt to manage the United States' growing psychiatric population by documenting how patients diagnosed with schizophrenia became a privileged object of study to explore the neurophysiological basis of mental illness. In my third chapter, finally, I will relate how the problem deep neural networks were designed to address was that of how best to organize work and labour in complex organizations like governments, highlighting how low-ranking government clerks became both key figures for, and the privileged targets of, the automation of government processes. Together, these different cases will allow to not only restore the various meanings and functions taken up by neural networks through time, but also highlight how their various iterations systematically manifested a broader concern with how to bring complex social problems under technoscientific control.

By approaching the history of neural networks through this expanded albeit situated lens, my dissertation will complement the current literature on artificial intelligence (AI) with not only a model-first approach to its study, but also an emphasis on the historical interplay between theories of human intelligence, conceptions of intelligent machines, and assumptions about human difference. Among historians of science, communication studies scholars, and media theorists, AI has been alternately situated in the context of the history of quantification[19], of Cold War

[19] e.g., Theodore Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton, NJ: Princeton University Press, 1995); Jacqueline Wernimont, *Numbered Lives: Life and Death in Quantum Media* (Cambridge, MA: The MIT Press, 2018).

computing practices[20], of the organization of labour along gender divides[21], or of the history of race and colonialism[22]. By locating AI at the intersection of such broader historical trajectories, these contributions have been key in historicizing both the ideas and practices underpinning AI while undermining ongoing claims around this technology's exceptionalism. And yet, by overlooking the individual models that constitute AI as well as the internal divergences underpinning its history, these studies have endowed this technology with a coherence that even its promoters would question. In the context of a technology whose power resides as much in its implementation as in the discourses surrounding it, this omission is especially critical as it ascribes to that technology "power that it does not yet have"[23]. Even among the few pieces focusing on individual models, only a handful have attended to the situated practices behind these models' development and implementation[24]. And despite the growing body of work on neural networks' intellectual history[25], rare are the studies that have addressed the experimental and other situated practices that this model both relied on and enabled[26].

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[20] e.g., Paul Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, MA: The MIT Press, 1996); Fred Turner, *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism* (Chicago, IL: University of Chicago Press, 2006).

[21] e.g., Mar Hicks, *Programmed Inequality: How Britain Discarded Women Technologists and Lost Its Edge in Computing* (Cambridge, MA: The MIT Press, 2017); Jennifer Light, "When Computers Were Women," *Technology and Culture* 40, no. 3 (1999): 455–82.

[22] e.g., Abeba Birhane, "Algorithmic Colonization of Africa," *SCRIPTed* 17, no. 2 (2020): 389–409; Paola Ricaurte, "Data Epistemologies, The Coloniality of Power, and Resistance," *Television & New Media* 20, no. 4 (2019): 350–65.

[23] Wendy Chun, *Control and Freedom: Power and Paranoia in the Age of Fiber Optics* (Cambridge, MA: The MIT Press, 2005), 9.

[24] e.g., Wendy Chun, *Discriminating Data: Correlation, Neighborhoods, and the New Politics of Recognition* (Cambridge, MA: The MIT Press, 2021); Stephanie Dick, "Of Models and Machines: Implementing Bounded Rationality," *Isis* 106, no. 3 (2015): 623–34; Brett Zehner, "A Liar's Epistemology: Herbert Simon's Performative Artificial Intelligence," *Qui Parle* 30, no. 1 (2021): 119–157.

[25] e.g., Clemens Apprich, "Secret Agents: A Psychoanalytic Critique of Artificial Intelligence and Machine Learning," *Digital Culture and Society* 4, no. 1 (2018): 29–44; Lily Kay, "From Logical Neurons to Poetic Embodiments of Mind: Warren S. McCulloch's Project in Neuroscience," *Science in Context* 14, no. 4 (2001): 591–614; Matteo Pasquinelli, "How to Make a Class: Hayek's Neoliberalism and the Origins of Connectionism," *Qui Parle* 30, no. 1 (2021): 159–184.

[26] e.g., Florian Jaton, "We Get the Algorithms of Our Ground Truths: Designing Referential Databases in Digital Image Processin," *Social Studies of Science* 47, no. 6 (2017): 811–40; Adrian Mackenzie, *Machine Learners: Archaeology of a Data Practice* (Cambridge, MA: The MIT Press, 2017).

Furthermore, by recentring the history of neural networks on the bodies and social problems my protagonists aimed to bring back under control, this project will complement the current literature on AI systems' amplification of racial and gender inequalities[27] with an in-depth exploration of how AI mediates the attribution of agency to certain bodies and populations at the expense of others. This literature's vital interventions are too often dismissed as temporary technological hiccups but the *longue durée* perspective this project advances highlights how AI's participation in the uneven distribution of intellectual potential extends beyond purely technical considerations. Once traced back to the colonial setting of 19th-century histology, the experimental turn of wartime psychiatry, and the convergence of computing research and management theory in the late 20th century, intelligence's rearticulation as a faculty that can be artificialized emerges as tightly intertwined with the biopolitical organization of intelligence along patterns of human difference. By revisiting this history, this project will detach artificial intelligence from long-lasting ideas about abstraction, objectivity, and computer-brain analogicity and instead emphasize how the knowledge it creates is oversaturated with assumptions about who or what is the bearer of intelligence. With this project, I thus aim to bring forward, locate, and hopefully interrupt the hegemonic project that neural networks have come to stand for, by questioning what they enable once they are recognized as a privileged model to represent things as varied as brains, learning machines, and complex systems of all kinds. For not only does the conceptualization of neural networks as universal machines obscure how it is their malleability—not their universality—that allows for their strategic deployment across contexts, but it also obfuscates the politics involved

[27] e.g., Ruha Benjamin, *Race After Technology: Abolitionist Tools for the New Jim Code* (Cambridge, UK: Polity Press, 2019); Safiya Umoja Noble, *Algorithms of Oppression: How Search Engines Reinforce Racism* (New York, NY: NYU Press, 2018).

in understanding, and intervening on, various contexts, social systems, and populations as networks of simple units.

CHAPTER 1—SPAIN, c. 1868-1910

MAPPING THE BRAIN:

ON RACIAL DIFFERENCE AND HYGIENE

IN NINETEENTH-CENTURY HISTOLOGY

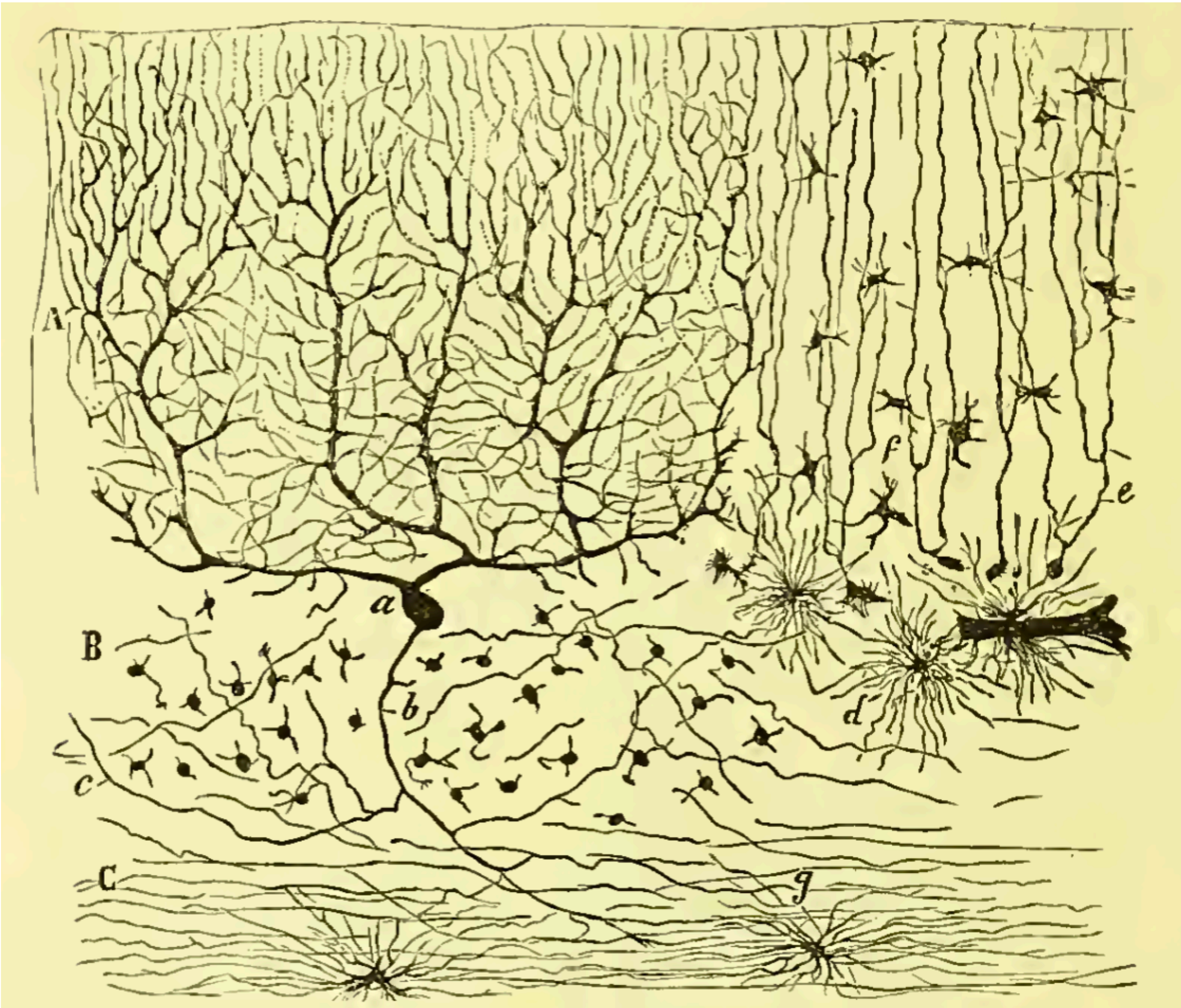

Figure 2. Drawing of Purkinje cells, stellate cells, and neuroglial cell, connected together across brain layers. From Santiago Ramón y Cajal, *Manual de Histología Normal y Técnica Micrográfica*. Valencia, Spain: Librería de Pascual Aguilar, 1889. p. 606.

1.1 Introduction

Neural networks' initial articulation in the context of 19th-century histology is also the one that is the most overlooked in both the historical and critical literature on artificial intelligence. While regularly referred to by its subsequent champions as the neurophysiological origin of their eponymous models[28], neural networks' first iteration as a model positing that all differences in mental potential across individuals were reducible to the interactions among discrete nerve cells is generally left unproblematized. But when first introduced, neural networks directly responded to growing anxieties about the biological basis of human and, more specifically, racial difference—or its lack, thereof. At a technoscientific level, their introduction coincided with key advances in microscopy and histology, which, far from illuminating meaningful physiological differences across racial divides, revealed undifferentiated tissues and structures at a microscopic scale. At a political level, their adoption unfolded alongside the gradual dissolution of many European colonial powers. From Gayatri Spivak to Sylvia Wynter, many have noted how this dissolution translated in the displacement of strict oppositions between Europeans and their colonized "Others" by more subtle "economic, political, and culturalist maneuvers"[29] that mapped these oppositions "onto the range of human hereditary variations and their cultures"[30]. At the intersection of both sets of events, neural networks introduced a more flexible model of both neurological and social organization, which not only reinscribed enduring racial hierarchies into the physiology of the brain in a more distributed form, but also recaptured colonized populations as privileged objects of foreign intervention under a medical and hygienic pretense.

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[28] e.g., McCulloch and Pfeiffer, "Of Digital Computers Called Brains"; David Rumelhart, James McClelland, and Geoffrey Hinton, "The Appeal of Parallel Distributed Processing," in *Parallel Distributed Processing, Volume 1* (Cambridge, MA: The MIT Press, 1986), 3–44.

[29] Gayatri Spivak, *A Critique of Postcolonial Reason: Toward a History of the Vanishing Present* (Cambridge, MA: Harvard University Press, 1999), 172.

[30] Sylvia Wynter, "1492: A New World View," in *Race, Discourse, and the Origin of the Americas: A New World View*, ed. Vera Lawrence Hyatt and Rex Nettlefort (Washington, D.C.: Smithsonian Institution Press, 1995), 34.

This emphasis on the colonial, racial, and sanitary underwriting of neural networks is key, as it allows to contextualize where the original impetus to look for difference in tissues where there appeared to be none came from, in a way that the usual emphasis on neurophysiology's tools and methods cannot. Among historians of science, the reconceptualization of the brain as a network of densely interconnected albeit independent neurons is generally located with the broader transformation of physiological knowledge throughout the late 19th century. In contrast with the neuroscientific literature, which frames the discovery of the neuron as the straightforward product of contemporaneous advances in microscopy[31], many historians have highlighted how these advances have instead been the object of lively debates and lasting conflicts regarding the meaning of the images they produced. While some have documented how a novel understanding of aesthetic emerged in response to the development of new tools designed to both envision the human body and expand its sensorium[32], others have noted how physiological knowledge became itself wholly dependent on the standardization of both visual methods and the interpretation of the inscriptions they produced[33]. In both cases, however, despite taking the controversy opposing neural networks to other neuroanatomical models as the *cause célèbre* of this broader transformation of physiological knowledge, very few of these scholars have attended to the broader social context that animated the search for such new fundamental structures. Be it by reducing neural networks to the product of methodological differences between its proponents and detractors[34] or framing them as a symptom of the growing prevalence of dead matter over living tissues in the study of

[31] e.g., Pablo Garcia-Lopez, Virginia Garcia-Marin, and Miguel Freire, "The Histological Slides and Drawings of Cajal," *Frontiers in Neuroanatomy* 4, no. 9 (2010): 1–16; Constantino Sotelo, "Viewing the Brain through the Master Hand of Ramón y Cajal," *Nature Reviews Neuroscience* 4 (2003): 71–77.
[32] e.g., Jonathan Crary, *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century* (Cambridge, MA: The MIT Press, 1990); Terry Eagleton, *The Ideology of the Aesthetic* (Oxford, UK: Basil Blackwell, 1990).
[33] e.g., Robert Brain, *The Pulse of Modernism: Physiological Aesthetics in Fin-de-Siècle Europe* (Seattle, WA: University of Washington Press, 2015); Evelyn Fox Keller, *Making Sense of Life: Explaining Biological Development with Models, Metaphors, and Machines* (Cambridge, MA: Harvard University Press, 2003).
[34] Lorraine Daston and Peter Galison, *Objectivity* (New York, NY: Verso, 2007), 120.

biology[35], historians of science have mostly overlooked the functions that neural networks were designed to fulfill outside of the laboratory.

And yet, in their initial formulation, neural networks were indeed singled out as an object of study through such experimental, visual, and technological means, but also, and more importantly, through various medical and hygienic practices targeted at the populations inhabiting Spain's colonies. When first introduced by Spanish histologist Santiago Ramón y Cajal in the 1888, neural networks specifically aimed to provide a biological explanation for the type of strict social stratifications he had witnessed throughout the Spanish empire. Beginning his career as a medical officer during the first Cuban war of independence, Ramón y Cajal transitioned to the study of neuroanatomy to account for the differences in mental potential he had perceived between Africans, Mulattos, Creoles, Cubans, and Spaniards during his deployment. Later, when promoting his new model, he defended neural networks' validity by claiming that other models couldn't account for the way the larger brain of certain populations did not correlate with greater intelligence compared to Europeans. By instead predicating intellectual potential on the richness of neural connections, Ramón y Cajal introduced neurons as the only fundamental structure capable to account for Europeans' superior intelligence over populations with a larger cranium. Finally, at the height of his scientific fame, Ramón y Cajal further refined his model while advising the Spanish government on the eradication of the many diseases endemic to Spain's colonies. Producing extensive studies of brain tissues taken from patients afflicted with neurological conditions such as the sleeping sickness, Ramón y Cajal used his model to construct the bodies of native populations as the bearers of a profound pathological difference that required sustained interventions from more developed nations.

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[35] Hannah Landecker, *Culturing Life: How Cells Became Technologies* (Cambridge, MA: Harvard University Press, 2010), 35–36.

Far from peripheral, these various events not only index the gradual displacement of strict racial hierarchies by more flexible conceptions of racial hygiene in Ramón y Cajal's work, but also map onto the transformation of Spain from a major colonial power to an empire in decline set on making up for the loss of its colonial possessions by enhancing its scientific prestige. As the flag bearer of Spain's scientific renewal, neural networks played a major role in the pursuit of this new ambition by providing a new model to study, identify, and ultimately eradicate the many neurological diseases allegedly inhibiting the racial uplifting of Spain's remaining colonies. But while many studies of colonial medicine have already documented similar shifts across Europe from a strict imperial model of military conquest, economic exploitation, and racial differentiation to a late-colonial model of population management based on racial uplifting and colonial hygiene, they tend to locate this "profound restructuring [… later] in the early-twentieth century"[36], roughly around the 1920s and 1930s. What neural networks' colonial history highlights, in contrast, is the development of a more contingent, dynamic, and flexible understanding of race in Spain as early as the 1890s, when Ramón y Cajal's strict racial hierarchies gave way to an understanding of racial underdevelopment as something that could be mitigated through appropriate medical, environmental, and social interventions. A handful of scholars have indeed similarly proposed to locate the rise of this more flexible view of race in the medical and sanitary discourses of the turn of the century[37], but few models incarnated these changes so readily as neural networks. From a neuroanatomical model whose units' organization mirrored the distributed albeit highly stratified

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[36] Ann Laura Stoler, *Carnal Knowledge and Imperial Power Race and the Intimate in Colonial Rule*, 2nd ed. (Berkeley, CA: University of California Press, 2010), 138; see also David Arnold, *Colonizing the Body: State Medicine and Epidemic Disease in Nineteenth-Century India* (Berkeley, CA: University of California Press, 1993); Deborah Neill, *Networks in Tropical Medicine: Internationalism, Colonialism, and the Rise of a Medical Specialty, 1890–1930* (Stanford, CA: Stanford University Press, 2012).

[37] see Warwick Anderson, *Colonial Pathologies: American Tropical Medicine, Race, and Hygiene in the Philippines* (Durham, NC: Duke University Press, 2006); Paul Kramer, "Blood Compacts: Spanish Colonialism and the Invention of the Filipino," in *The Blood of Government: Race, Empire, the United States, & the Philippines* (Chapel Hill, NC: The University of North Carolina Press, 2006).

social structure of colonial Cuba, neural networks evolved into a model of influence applicable to both nations and nerve cells, which conceived of the relationships among them as not only more reciprocal and malleable in nature, but also available to purposeful management and external manipulation.

To explore these themes, this chapter will examine how neural networks' reformulation from a neuroanatomical model of racial difference to a rationale for Spain's renewed involvement in both its former and current colonies indexed not only the rise of neurophysiology as a field but also broader changes in the scope, aims, and practices of colonial science. To do so, it will document the various conditions that motivated the search for difference in otherwise undifferentiated tissues, as well as reconstitute the experimental, visual, and managerial practices neurons both relied on, and enabled, throughout their reification as an object of knowledge. First, it will contrast neural networks with the other neuroanatomical model it initially opposed—namely, nervous networks, then championed by Italian physician Camillo Golgi. Looking into the specific techniques used to capture and envision neurons, it will argue that the difference between both approaches wasn't so much a matter of visual interpretation but instead of how Ramón y Cajal and Golgi respectively perceived the dead bodies they worked with. Second, it will attend to the highly racialized worldview that underpinned Ramón y Cajal's search for new fundamental structures in the brain. Relating Ramón y Cajal's extensive accounts of the social organization of life in the colonies to his transition to neuroanatomy, it will highlight how the original impetus to look for such structures resulted from Ramón y Cajal's attempt to provide a biological basis for the latter. Finally, it will attend to how neural networks came to be perceived as a sanitary rationale for the development of new managerial practices in Spain's last colonies in the Gulf of Guinea. By documenting how Ramón y Cajal's later views of neural plasticity reflected his more flexible understanding of race, it will highlight how neural networks came to embody a late-colonial model of population management, which recast previous ideas about racial difference into the language of modern medicine and hygiene.

Together, these different sections will demonstrate that neural networks' first iteration wasn't so much the straightforward product of empirical observations as a complex experimental construct produced through both the careful manipulation of human tissues and the development of new sanity policies designed to racially uplift colonized populations. By guiding practices as diverse as silver staining and sanitary policies, neural networks provided a highly operational device to maintain uneven power relations at both a micro- and a macroscopic scale. Part experimental, part speculative, neural networks not only reflected a wide range of anxieties vis-à-vis racial difference, contagion, and imperial decline, but also initiated a broader reconceptualization of biological life in terms of fundamental structures that could be intervened on. For beyond their introduction of the neuron as a new fundamental unit capable to explain a wide range of biological, social, and geopolitical phenomena, neural networks also instituted dead matter into a model organism for living processes, racialized bodies into stand-ins for various stages of human development, and whole populations into experimental subjects for new ideas about, and measures of, racial hygiene. If most contemporary accounts of Ramón y Cajal's neural networks overlook the broader colonial framework in which they emerged and operated, it is then despite their clear role in mediating how certain bodies were not only constructed as racialized and pathologized, but also rendered available for foreign interference and intervention. By documenting this history, this chapter then proposes to map the rise of neurophysiology as a field onto a broader transformation of race science and colonial management in the late 19th century, with the aim of highlighting the role of the latter in providing an impetus for the development of the former.

1.2 Envisioning the Body: From Standardized Images to Fixated Tissues

For an event known for celebrating some of the greatest scientific breakthroughs, the 1906 Nobel Conference was surprisingly full of conflict and controversies. On December 10, 1906, two leading scientists—Spanish histologist Santiago Ramón y Cajal and his Italian counterpart Camillo Golgi—convened to Stockholm to jointly receive the Nobel Prize in Physiology for a discovery they themselves disagreed on. While selected for their pioneering work in neuroanatomy, the two figures promoted widely distinct understandings of the brain's fundamental structure. Golgi, on the one hand, defended the "reticular theory," which suggested that the brain was composed of a continuous network of nervous fibres. Ramón y Cajal, on the other hand, championed the "neuron doctrine," introduced two decades earlier, which posited that the brain was made of intricately connected albeit independent cell-like units. Meeting each other for the first time at the ceremony, the two honourees broke with the Nobel Conference's protocol by delivering lectures full of sharp criticisms of one another's work. Speaking first on the night of the 11th, Golgi reaffirmed his understanding of the brain as "a diffuse nervous network"[38] while dismissing "the widespread individualization of the brain's elements" as "an old, bygone theory"[39]. Speaking the following day and, as he recalled, "trembling with impatience [… to offer] a suitable and clear correction of so many odious errors"[40], Ramón y Cajal dismissed his co-awardee's theory as the product of

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[38] Camillo Golgi, *La Doctrine Du Neurone : Théorie et Faits* (Stockholm, Sweden: Imprimerie royale P.-A. Norstedt & Fils, 1907), 14.
[39] Golgi, 30.
[40] Santiago Ramón y Cajal and E. Horne Craigie (translator), *Recollections of My Life* (Cambridge, MA: The MIT Press, 1989), 553.

"incomplete methods far less comprehensive"[41] than his own. Reducing reticular theory to a hypnosis-like, "irresistible suggestion"[42], Ramón y Cajal framed his "neural network"[43] as the anatomically accurate, objective counterpart to Golgi's nervous network—one of the many "scientific errors professed in good faith" by his esteemed colleague[44].

But beyond the personal dispute between the two awardees, what this episode crystallized is the persistence of the very same problems of interpretation both figures spent their whole careers trying to overcome. Inspired by the work of Robert Koch and Louis Pasteur, Golgi and Ramón y Cajal shared a similar faith in the capacity of new visual techniques to settle anatomical questions[45]. In the name of providing representations of the brain that would be not only more minute but also devoid of subjective interference, they developed highly standardized methods whose aim consisted in turning human tissues into stable images. Among them, the most notable one was a staining technique they both relied on, which was first introduced by Golgi in 1873 before being improved upon, and popularized, by Ramón y Cajal in 1889. Known as the "black reaction," it consisted in fixating thin slices of brain tissues by immersing them in potassium dichromate, soaking them in a solution of 0.5 to 1% of silver nitrate until they acquired a black coloration, and finally observing the newly fixated structures under a microscope[46]. And yet, while they both agreed that this method allowed to "demonstrate even to the blinds the structures" of the brain[47], they still disagreed on the type of structure it revealed and accused one another of seeing

[41] Ramón y Cajal, "Structure et Connexions Des Neurones," 19.
[42] 19.
[43] 7.
[44] 21.
[45] See Camillo Golgi, *Sulla Origine Centrale Dei Nervi* (Naples, Italy: Enrico Detken Editore, 1881), 3–6; Santiago Ramón y Cajal, *Manual de Histología Normal y Técnica Micrográfica* (Valencia, Spain: Librería de Pascual Aguilar, 1889), 14–57.
[46] Camillo Golgi, *Sulla Struttura Della Sostanza Gricia Del Cervello* (Milan, Italy: Stabilumento Dei Fratelli Rechiedei, 1873), 3.
[47] Golgi quoted in, and translated by, Paolo Mazzarello, "Camillo Golgi: The Conservative Revolutionary," *Italian Journal of Anatomy and Embryology* 124, no. 3 (2019): 273.

things that simply weren't there. At their core, both neural and nervous networks thus essentially boiled to a matter of visual interpretation for Golgi and Ramón y Cajal, for whom physiological questions were indistinguishable from visual ones.

In Ramón y Cajal's case, this particular view emerged from a long and convoluted journey into the field of medicine and, later, histology. Born in 1852 in rural Spain, Ramón y Cajal manifested—or, at least, prided himself of manifesting—a passion for the arts from a young age. Prohibited by his father Dr. Justo Ramón Casasú to pursue his artistic ambitions, however, Ramón y Cajal followed his father's steps and began his medical studies in 1868. A disciplined if unmotivated student, Ramón y Cajal found pleasure in the study of human anatomy for the way it provided him with the opportunity to combine his artistic ambitions with his medical training. Scavenging human remains with his father from various abandoned cemeteries, Ramón y Cajal produced throughout his studies hundreds of detailed sketches of human tissues, organs, and bones of all kinds[48]. Pleased with son's application in the study of human anatomy, Ramón Casasú volunteered in the Provincial Medical Service of Zaragoza—a public service providing medical assistance to the province's peasantry and working poor—in exchange of temporary positions for both himself and Ramón y Cajal at the University of Zaragoza. There, while working under his father's guidance and completing his medical degree, Ramón y Cajal was introduced to the practice of dissection and focused primarily on structures whose complexity appealed to his "aesthetic sensibility"[49]. Working primarily with individual organs and tissues, Ramón y Cajal produced detailed watercolours of intricate structures such as ganglia, plexuses, and individual nerves, in the hope of producing the first comprehensive atlas of anatomy to be published in Spain.

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[48] See Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 144–45.
[49] Ramón y Cajal and Craigie (translator), 168–70.

It is during this period that Ramón y Cajal first articulated his theory of observation, which posited that the accuracy and scientific value of physiological observations could only be ensured through the production of anatomical drawings and images. For him, drawings, sketches, and watercolours were precisely what "provid[ed] an objective basis" to the study of anatomy[50]. More than simple representations, such images consisted in a privileged way to not only ensure the accuracy and soundness of physiological observations, but also give the latter the stability they otherwise lacked. Later, at the height of his debate with Golgi, Ramón y Cajal even argued that the validity of his theory was in part confirmed by the greater ease with which individual neurons could be drawn compared to dense meshes of continuous fibres. In an especially telling series of drawings comparing the structural assumptions of reticular theory with those of his neuron doctrine[51], Ramón y Cajal's representation of the former amounted to little but undifferentiated webs of lines and doodles. Contrarily to his carefully drawn, clearly differentiated neurons, Ramón y Cajal's sketches of nervous networks altogether desisted from providing an accurate representation of what such a structure might look like, as if incompatible with the medium of drawing itself. Not only did reticular theory appear in these sketches as beyond representation itself, but it is also on that basis that Ramón y Cajal concluded that Golgi's theory was "equivalent to declaring the absolute unsearchability of the organ of the soul"[52]. With Ramón y Cajal attributing to his Zaragoza years his profound conviction that "that which comes through the eyes is impressed very firmly"[53], it is then a highly visual understanding of physiological knowledge which emerged from his first engagement with both dissection and anatomical drawing—one

[50] Ramón y Cajal and Craigie (translator), 338.
[51] Many of these drawings can be found in Eric Newman, Alfonso Araque, and Janet Dubinsky, *The Beautiful Brain: The Drawings of Santiago Ramón y Cajal* (New York, NY: Abrams, 2017), 146–47.
[52] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 338.
[53] Ramón y Cajal and Craigie (translator), 147f.

which framed the act of turning the body into a stable image into the defining endeavour of physiology.

But while Ramón y Cajal ascribed the differences between his theory and that of Golgi to such partly methodological, partly epistemological considerations, he mostly ignored the very objects whose structures he so persistently aimed to capture—namely, dead human bodies. Many historians of science have documented the gradual displacement of living bodies by dead matter as the privileged object of anatomical studies throughout the 19th century[54] but what Ramón y Cajal's early anatomical work highlighted was how the latter's recognition as raw biological matter available for anatomical studies was actively mediated by conceptions of human difference. For someone who later modelled neural independence on human individuality[55], Ramón y Cajal failed to attribute much individuality to the deceased bodies he so closely scrutinized and drew. Working with tissues taken from deceased patients of the Santa Engracia Hospital where he and his father worked, which primarily served the peasantry of Zaragoza's outskirts, Ramón y Cajal saw in these bodies little but the "marvellous workmanship of life"[56]. Even later in his career, when he became a self-proclaimed champion of the Spanish peasantry, Ramón y Cajal still struggled to recognize them as complete individuals by repeatedly characterizing poverty as a disease that should be eradicated through the sterilization of the working poor[57]. While sympathetic to "that repressed hatred […] which the poor worker feels toward the burger and the professional man"[58], Ramón y Cajal then nevertheless adopted the bodies of lower-class workers as undifferentiated model

[54] e.g., Keller, *Making Sense of Life: Explaining Biological Development with Models, Metaphors, and Machines*, 215–16; Landecker, *Culturing Life: How Cells Became Technologies*, 35.
[55] See Santiago Ramón y Cajal, *Elementos de Histologia Normal y de Técnica Micrográfica* (Madrid, Spain: Moya, 1904), 189.
[56] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 169.
[57] See Santiago Ramón y Cajal and Laura Otis (translator), "For a Secret Offense, Secret Revenge," in *Vacation Stories* (Champaign, IL: University of Illinois Press, 2001), 35–37.
[58] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 27.

organisms for his anatomical studies, anticipating the highly stratified view of human development that later animated his neuroanatomical theories.

Tellingly, Ramón y Cajal's view contrasted with that of Golgi, who was keenly aware of the type of bodies he was working with. Contrarily to Ramón y Cajal, Golgi mobilized drawing and other visual techniques not so much as means to validate anatomical observations but instead as part of his ambition to turn psychiatry into a scientific practice. Beginning his career as a rural doctor, Golgi transitioned to the study of anatomy in the late 1860s as part of a broader attempt to provide an objective basis for the diagnosis of mental illness. Working at the University of Pavia's Department of Psychiatry, Golgi produced his first anatomical drawings while trying to document structural differences in the brain of mental health patients[59]. By the time he developed his famous staining method, Golgi had already articulated a research agenda centred on the etiology of mental diseases and as such produced his first silver-stained studies on the brains of patient having suffered from cognitive impairment and chorea[60], which were then both understood as mental diseases. While remembered for his anatomical studies of the brain at large, Golgi nevertheless remained specifically committed to the more targeted project of exhaustively documenting all possible variations the structure of the brain. As he later commented, Golgi conceived of his work as the "positive and experimental" alternative to the "predominantly philosophical-speculative tendencies in the study of mental diseases"[61], whose reliance on patient history and therapy he deemed incompatible with psychiatry's growing recognition as both a medical and scientific practice. More than means to produce and stabilize anatomical knowledge, drawing and staining

[59] See Camillo Golgi, "Sull'eziologia Delle Alienazioni Mentali in Rapporto Alla Prognosi Ed Alla Cura," *Annali Universali Di Medicina* 71 (1869): 564–633.
[60] Camillo Golgi, "Sulla Struttura e Sullo Sviluppo Degli Psammomi," *Morgagni* 11 (1869): 874–86; Camillo Golgi, "Sulle Alterazioni Degli Organi Centrali Nervosi in Un Caso Di Corea Gesticolatoria Associata Ad Alienazione Mentale," *Rivista Clinica* 2, no. 4 (1874): 361–77.
[61] Golgi quoted in, and translated by, Paolo Mazzarello, *Golgi: A Biography of the Founder of Modern Neuroscience* (Oxford, UK: Oxford University Press, 2009), 387.

thus consisted for Golgi in promising tools to diagnose and eventually treat the many patients confined to lifelong institutionalization he encountered.

From the very beginning, Golgi and Ramón y Cajal did not then so much differ in the visual techniques they deployed or in their vision of the latter as in how they conceived of the human remains they studied. Both indeed employed human cadavers as the model organisms for their studies of human physiology but with key differences. Whereas Golgi's studies focused on highly individualized albeit pathologized bodies, Ramón y Cajal's, for their part, promoted a view of lower-class workers' bodies as privileged objects to differentiate complex structures from one another, while representing a stage of human development that itself preceded meaningful individuality and differentiation. These nuances remained throughout their careers and more importantly informed the developments of their respective research. For once Ramón y Cajal finally obtained his medical degree in 1873, his particular view of certain bodies as undifferentiated matter available to differentiate various tissues and organs from one another was only further confirmed by his experience serving in the Spanish military. Enrolled into the Spanish army as a medical officer right after his graduation, Ramón y Cajal spent a few months pursuing Carlist rebels across Catalunya along with the rest of his regiment before volunteering to be sent to colonial Cuba, where the first Cuban war of independence was being fought. It is there that Ramón y Cajal not only transitioned to the study of histology, but also aligned his socially inclined view of human biology with the broader colonial worldview organizing 19th-century Cuban society. Interpreting the organization of Cuban society as a reflection of the stratified structure of human development, Ramón y Cajal saw the social organization of colonial Cuba as a proof of the fundamental racial qualities embodied by the colony's different social classes. At a time when studies of the brain exposed little more than "the colourlessness, the uniformity of refractive index, and the simplicity of architecture of a mass of jelly"[62], it was this encounter with life in the colonies that led Ramón y Cajal to look for difference where there appeared to be none.

1.3 Ramón y Cajal in Cuba: Biologizing Social Hierarchies

Compared to his literary work[63], psychoanalytically inclined theory of the mind[64], and politico-philosophical commitments[65], which have all been the objects of sustained academic attention, Ramón y Cajal's participation in the Spanish colonial project has been mostly overlooked in the literature. And yet, Ramón y Cajal shared with many of his contemporaries a highly hierarchical view of human biology combined with a general enthusiasm for European colonial expansion. The reasons for this omission can only be speculated upon but certainly extend beyond the scope of Ramón y Cajal's work and career alone. For while many scholars have framed the Spanish scientific revolution as a direct response to the discovery of new plants, animals, and peoples in colonial America[66], few have attended to the colonial motivations underpinning the aims and practice of science in the Spanish empire beyond the 18th century. Overwhelmingly characterized as a period of decline by historians of science, the 19th century witnessed Spain's loss of most of its colonial possessions. But as Jorge Cañizares-Esguerra notes, Spain was still for most of that period a widespread empire with colonies in the Caribbeans, the Pacific, and Africa

[62] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 526.
[63] e.g., Laura Otis, "Introduction," in *Vacation Stories*, 2001, vii–xxiii; Dale Pratt, *Signs of Science: Literature, Science, and Spanish Modernity Since 1868* (West Lafayette, IN: Purdue University Press, 2001).
[64] e.g., Benjamin Ehrlich, *The Dreams of Santiago Ramón Y Cajal* (Oxford, UK: Oxford University Press, 2016); Mazzarello, *Golgi: A Biography of the Founder of Modern Neuroscience*.
[65] e.g., Laura Otis, *Membranes: Metaphors of Invasion in Nineteenth-Century Literature, Science, and Politics* (Baltimore, MD: Johns Hopkins University Press, 1999); Tomás Perrín, "Cajal Como Español," *Abside* 22 (1958): 191–216.
[66] See, for instance, Antonio Barrera-Osorio, *Experiencing Nature: The Spanish American Empire and the Early Scientific Revolution* (Austin, TX: University of Texas Press, 2006); Daniela Bleichmar, *Visible Empire: Botanical Expeditions & Visual Culture in the Hispanic Enlightenment* (Chicago, IL: University of Chicago Press, 2012).

alike[67]. Despite their reduced size and number, these colonies all had major economic and political import to metropolitan Spain, which continued to sponsor a wide range of scientific endeavours to further colonial institutions' knowledge of these territories' local ecologies, peoples, and resources[68]. If anything, this period coincided with the rise of local scientific elites, which promoted agendas increasingly distinct from those of Spanish authorities. While local elites in Cuba, Puerto Rico, and the Philippines subsidized the creation of local academies of science with the aim of increasing both their industrial development and political autonomy[69], Spanish administrators, for their part, sponsored the creation of new medical institutions dedicated to enhancing the hygienic conditions in the colonies[70].

If few have given any proper attention to Ramón y Cajal's own contribution to, and investment in, colonial science, it might then very well be because of the general blind spot surrounding 19th-century science in the Spanish empire. Except for Cañizares-Esguerra, who relates the rise of a distinctive form of "modern colonial science" in metropolitan Spain to the growing political autonomy of its colonies[71], accounts of Spanish colonial science in the 19th century have mostly defined this "modern" shift by the growing influence of native scientists. Scholars like Kapil Raj, for instance, have employed the term modern colonial science to refer to "the construction and spread of scientific knowledge through reciprocal, albeit asymmetric,

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[67] Jorge Cañizares-Esguerra, *Nature, Empire, and Nation: Explorations of the History of Science in the Iberian World* (Stanford, CA: Stanford University Press, 2006), 7.

[68] See Antonio Lafuente and Jose Catala, "Ciencia Colonial y Roles Profesionales En La América Española Del Siglo XVIII," *Quipu* 6, no. 3 (1989): 387–403; Miguel Puig-Samper, *Crónica de Una Expedición Romántica Al Nuevo Mundo: La Comisión Científica Del Pacífico (1862–1866)* (Madrid, Spain: CSIC, 1988).

[69] See Stuart McCook, *States of Nature: Science, Agriculture, and Environment in the Spanish Caribbean, 1760-1940* (Austin, TX: University of Texas Press, 2002); Pedro Pruna, "National Science in a Colonial Context: The Royal Academy of Sciences of Havana, 1861- 1898," *Isis* 85, no. 3 (1994): 412–26.

[70] See Kramer, "Blood Compacts: Spanish Colonialism and the Invention of the Filipino."

[71] Cañizares-Esguerra, *Nature, Empire, and Nation: Explorations of the History of Science in the Iberian World*, 46–63; see also Alberto Elena and Javier Ordóñez, "Science, Technology, and the Spanish Colonial Experience in the Nineteenth Century," *Osiris* 15 (2000): 70–82.

processes of circulation and negotiation" between Spain and its colonies, with the aim of undermining the "diffusionist" model that previously characterized historical studies of science in European colonies[72]. But what Ramón y Cajal's research hinted at was rather a distinctive form of late-colonial science which, in continuity with Cañizares-Esguerra's own interpretation, responded to the ongoing transformation of Spain's relationship with its colonies. Combining a belief in sanitation and colonial hygiene with a more flexible view of race, Ramón y Cajal developed his distinctive approach to neurophysiology as part of what Warwick Anderson describes as "a distinctive late-colonial mode of population management"[73]—one specifically devised to recast enduring racial distinctions in a more flexible form.

Having never left the Iberian Peninsula before, Ramón y Cajal welcomed with great enthusiasm the opportunity to see "the people and the customs of foreign lands"[74]. Upon his arrival, however, Ramón y Cajal's first impressions concerned not the local cultures or populations but instead the social organization of the colony. Marvelling at the Andalusian character of the Cuban capital and its people—"sensitive and visionary, but languid and indolent"—Ramón y Cajal listed as La Habana's only defect that it had not been first colonized by "the strong racial material in [Spain's] northern parts, which is more industrious, thrifty, and highly prolific [… than] the people of Andalusia"[75]. As a reflection of peninsular Spain's own social structure and "mixture of races"[76], colonial Cuba stood for Ramón y Cajal as a clear example of the biological basis of such distinctions, which were there more clearly manifested given the greater racial disparities among

[72] Kapil Raj, *Relocating Modern Science: Circulation and the Construction of Knowledge in South Asia and Europe, 1650-1900* (London, UK: Palgrave Macmillan, 2010), 13; see also Waltraud Ernst, "Beyond East and West: From the History of Colonial Medicine to a Social History of Medicine(s) in South Asia," *Social History of Medicine* 20, no. 3 (2007): 505–524.
[73] Anderson, *Colonial Pathologies: American Tropical Medicine, Race, and Hygiene in the Philippines*, 4.
[74] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 204.
[75] Ramón y Cajal and Craigie (translator), 211.
[76] Ramón y Cajal and Craigie (translator), 211.

the peoples inhabiting the island. These early sociobiological reflections are key, as they anticipated the sociologically inclined theory of biology and neurology that Ramón y Cajal articulated following his deployment. Later describing the brain as a "restless beehive which we all have within us"[77], Ramón y Cajal proposed to understand neurons as akin members of a society who, "in their subordination to an organic whole, enjoy a certain level of functional autonomy"[78]. But far from equalitarian, the type of social order Ramón y Cajal imagined as mirroring the organization of neurons was tightly informed by the highly stratified social structures he witnessed in Cuba, as illustrated by his extensive accounts of the various groups constituting Cuban society.

A few months into his deployment, which had led him to travel from La Habana to Puerto Principe and finally Vista Hermosa in central Cuba, Ramón y Cajal began articulating his sociologically inclined theory of racial difference. Witnessing little fighting beyond the daily shots exchanged between insurgents and his camp's sentries, Ramón y Cajal documented in great detail his observations on the distribution of work and labour in the Caribbean colony, which he interpreted as a proof of the fundamental racial qualities embodied by the colony's different classes. At the bottom of the island's hierarchy, Ramón y Cajal identified "the native race," which occupied the most remote parts of the island and mostly partook in subsistence farming, and "the Africans and Mulattos," whose physical strength made especially well adapted to agricultural labour[79]. Then, he listed the Creoles, i.e., landowners of mixed but mostly Spanish descent, whose exposure to tropical conditions over several generations had turned into "pale hothouse plants living indolently and parasitically"[80]. On top of them, Ramón y Cajal singled out the Cubans—

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[77] Ramón y Cajal and Craigie (translator), 291.
[78] Ramón y Cajal, *Elementos de Histologia Normal y de Técnica Micrográfica*, 189.
[79] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 212.
[80] Ramón y Cajal and Craigie (translator), 212; It is worth emphasizing that the term "Creole" was undergoing a profound transformation at this point in time. While initially referring to the people of Spanish descent born in colonial America, it had come to encompass by the late 19th century all America-born people independently of their ethnic background. This change was symptomatic of growing tensions between the colonies and peninsular Spain, which

natives of the island with recent and direct European ancestry—who, "confined to the city and engaged in business or professional work"[81], possessed the necessary intellect and local knowledge to act as mediators between colonial Cuba and peninsular Spain. And supplanting all of them, Ramón y Cajal finally located peninsular Spaniards like himself, who, despite their vulnerability to "the enervating effects of the climate," dominated all the other groups by their superior "[intellectual] vigour"[82]. Framing the island's social organization in racial terms and, in the case of the Creoles and Cubans, in degrees of whiteness, Ramón y Cajal posited a certain model of human development defined not only by the gradual substitution of physical robustness by intellectual vigour but also by the will and growing capacity to tame even the most inhospitable of environments. While mostly absent from the island, which he described as "simply uninhabitable for the European," the "white race"[83] remained for Ramón y Cajal the rightful owner of the colony given both its alleged intellectual superiority and its capacity to gradually render the island more habitable for itself.

Such an account is indeed representative of the type of highly racialized worldview that characterized most scientific writings and travel logs of the time. Like in many such texts, it viewed "native and mixed-blood 'character' […] as fixed in a way that European 'character' was not"[84] by framing the latter as actively shaping the world it inhabited in a way other populations couldn't. But already then, Ramón y Cajal foresaw a new social order revolving not on static racial hierarchies and sheer military force but rather on both the racial uplifting of native and African

had prohibited all Creoles—including those of Spanish descent—to occupy any positions in Cuba's colonial government. See Mary Louise Pratt, *Imperial Eyes: Travel Writing and Transculturation*, 2nd ed. (Milton Park, UK: Routledge, 2008).

[81] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 212.

[82] Ramón y Cajal and Craigie (translator), 212–13.

[83] Ramón y Cajal and Craigie (translator), 205.

[84] Stoler, *Carnal Knowledge and Imperial Power Race and the Intimate in Colonial Rule*, 138; see also Arnold, *Colonizing the Body: State Medicine and Epidemic Disease in Nineteenth-Century India*.

populations and the protection of European settlers from the tropical climate's deleterious effects[85]. In a passage discussing Spain's military doctrine, which consisted in dividing up the island and its peoples through a network of blockhouses and forts connected through fortified roads, Ramón y Cajal deplored how the resources invested for these fortifications should have instead been used to build biomedical laboratories, sanitary facilities, and modern hospitals[86]. More than insurgents, it was diseases such as malaria and the mosquitoes carrying them that Ramón y Cajal recognized as the main threats to the colony[87]. In addition to killing and disabling thousands of Spaniards and Cubans every year, these diseases were for Ramón y Cajal what maintained the colony's local population in a state of underdevelopment. With the right facilities and sanitary policies, however, which would allow to study, treat, and ultimately eradicate these diseases, Ramón y Cajal believed that the racial makeup of certain groups—mainly Mulattos and white Creoles—could be eventually improved and allow for the Cuban colonial government to "pass from a tutorial rule to an assimilative one"[88].

This new social geography that Ramón y Cajal imagined between Spain and its colonies was indeed far from being an inclusive or more equalitarian one—on the contrary. As noted by many historians of colonialism, such "liberal" approaches to colonial management framed such civilizing processes as *longue durée* ones, which deferred any form of local autonomy into some

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[85] In an especially telling passage, Ramón y Cajal discussed how the Creoles had "degenerate[d] rapidly" under the tropical climate and, lacking the "repeated admixtures of European blood," had lost the vigour and intellect of their white ancestors. See Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 212–13.
[86] Ramón y Cajal and Craigie (translator), 224–26.
[87] If Cuba was devoid of any clear sanitary policy at the time of Ramón y Cajal's arrival, it was because of the recent dissolution of all local institutions dedicated to controlling the diseases endemic to the island. Founded in the 1860s to fight the cowpox pandemic that was then afflicting the Cuban population, La Habana's Royal Academy of Science had, for instance, been dissolved in 1871 because of its role in having provided a space for the Creole medical elite to organize into a coherent political force in support of the insurgents. See Stephanie Gonzalez, "The Cowpox Controversy: Memory and the Politics of Public Health in Cuba," *Bulletin of the History of Medicine* 29, no. 1 (2018): 110–40.
[88] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 228.

distant and unspecified future while justifying an ever more minute regulation of colonized populations and their relationships[89]. But what it did introduce in the context of Ramón y Cajal's work, however, was a more flexible understanding of biology and, more specifically, human development than what previously animated his social views. Away from the clear racial stratifications that underwrote his initial perception of social organization in both Spain and colonial Cuba, Ramón y Cajal embraced a more fluid view which recognized the possibility of uplifting certain racial groups should the right sanitary policies be put in place. At that point in time, however, Ramón y Cajal's early sanitary ambitions were cut short. Suffering from an acute case of malaria aggravated by repeated episodes of dysentery, Ramón y Cajal requested to be officially discharged in 1875 before any of the many sanitary recommendations he submitted to the local government—from the provision of mosquito nets to soldiers to the drying out of the island's countless swamps and mashes—be heard let alone adopted. Sailing back to Spain with a portfolio full of drawings of the local fauna, the island's peoples, and himself, Ramón y Cajal returned to civilian life with a conception of science and medicine as not only central to the uplifting of the "lower races" by the greater ones, but also intimately involved in making, as he wrote, "colonization defensible if not desirable"[90].

1.4 The Experimental Body: From Isolating Bacteria to Managing Populations

Back in Spain, Ramón y Cajal returned to Zaragoza and set his mind on joining the academic profession. Physically weaken by malaria, dysentery, and tuberculosis, Ramón y Cajal

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[89] e.g., Uday Mehta, "Liberal Strategies of Exclusion," in *Tensions of Empire: Colonial Cultures in a Bourgeois World*, ed. Frederick Cooper and Ann Laura Stoler (Berkeley, CA: University of California Press, 1997), 59–86; Bhiku Parekh, "Liberalism and Colonialism: A Critique of Locke and Mill," in *The Decolonization of Imagination*, ed. Jan Nederveen Pieterse and Bhiku Parekh (London, UK: Zed Books, 1995), 81–95.
[90] Santiago Ramón y Cajal, "Prólogo," in *Informe de La Comisión Del Instituto Nacional de Higiene de Alfonso XIII Enviada a Las Posesiones Españolas Del Golfo de Guinea Para El Estudio de La Enfermedad Del Sueño y de Las Condiciones Sanitarias de La Colonia*, ed. Gustavo Pittaluga (Madrid, Spain: Blass, 1910), 13.

quickly abandoned all hopes of pursuing a career as a practising physician and instead enrolled in the necessary courses to obtain a doctor's degree in a field specifically concerned with the type of microscopic entities that had afflicted him during his deployment—namely, histology. Many scholars have attended to the social and technical work that was involved in establishing histology as a recognized discipline in national settings such as Germany[91] and the United Kingdom[92] in the 1840s but few have attended to field's delayed adoption in the Spanish academy. According to Ramón y Cajal, histology was still by the late 1870s a new and ill-perceived field in Spain, where vitalism remained the dominant doctrine in most universities and medical institutions. Concerned with the developmental qualities of life, this doctrine's adherents favoured the study of whole organisms and living subjects while remaining skeptical of the veridical status of microscopic preparations, which they described as "pure fantasy"[93]. For Ramón y Cajal, such studies of living organisms remained too limited, however, as they failed to reveal the type of "parasitic life" that had afflicted him and his fellow soldiers while abroad[94]. As he then wrote, living matter was for him "hidden obstinately in the double invisibility of smallness and homogeneity," with the formidable complexity of biology being reduced to "the colourlessness, the uniformity of refractive index, and the simplicity of architecture of a mass of jelly"[95]. Histological techniques, in contrast, which fixated biological tissues in order to protect them from both decay and movement, represented for him a privileged means to make delicate structures "stand out

[91] e.g., Nick Hopwood, "'Giving Body' to Embryos: Modeling, Mechanism and the Microtome in Late Nineteenth Century Anatomy," *Isis* 90 (1999): 462–496.
[92] e.g., L. Stephen Jacyna, "'A Host of Experienced Microscopists': The Establishment of Histology in Nineteenth-Century Edinburgh," *Bulletin of the History of Medicine* 75 (2001): 225–253.
[93] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 252.
[94] Ramón y Cajal and Craigie (translator), 217.
[95] Ramón y Cajal and Craigie (translator), 527.

energetically from an uncoloured background"[96] and thus reveal the microscopic threats facing the human race—or, so he believed, races.

Following his courses in histology remotely, as they were then only offered in Madrid, Ramón y Cajal volunteered as an auxiliary at the only laboratory equipped with a modern microscope in the whole of Aragón—namely, the University of Zaragoza's laboratory of physiology. There, he produced his first histological preparations, which were tellingly of blood cells infected with malaria[97]. Not yet familiar with Louis Pasteur's earlier work not with Robert Koch's contemporaneous research on germ theory, Ramón y Cajal developed throughout that period his own peculiar view of the "captivating scenes in the life of the infinitely small"[98], which he conceived of as both a threat to, and a mirror image of, the broader social milieu he inhabited. Writing that "humankind can only protect itself against the enemy that it knows"[99], Ramón y Cajal developed his mastery of histological techniques with the aim of not only identifying "the invisible parasites"[100] that had afflicted him in Cuba, but also serving the broader colonial project he had been part of. Likening any disease to a "frontier skirmish or a city riot"[101], Ramón y Cajal developed an understanding of the human body as itself akin to an empire defending itself against those threatening its integrity. Elaborating on this analogy, he more specifically compared white cells to "local powers" responsible for managing outbreaks "with little or no intervention from the central authorities, […] represented by the nervous system"[102]. Producing his subsequent histological preparations with white blood cells, Ramón y Cajal proposed in his first published

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[96] Ramón y Cajal and Craigie (translator), 527.
[97] Ramón y Cajal and Craigie (translator), 251–52.
[98] Ramón y Cajal and Craigie (translator), 252.
[99] Santiago Ramón y Cajal, "Prológo," in *Desinfección Doméstica: Aislamiento y Desinfección Simplificados*, ed. Carlos Vicente y Charpentier (Madrid, Spain: Fortanet, 1901), vii.
[100] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 252.
[101] Ramón y Cajal and Craigie (translator), 175.
[102] Ramón y Cajal and Craigie (translator), 175.

work to understand the latter as akin to military brigades both searching for, and hunting down, hidden threats, thus performing at a microscopic level what empires like Spain were accomplishing at a macroscopic one[103].

This imperial view of the body, which Ramón y Cajal formulated while producing detailed studies of both various parasites and leukocytes, was shortly after put to the test during the cholera epidemics of the 1880s. Recently appointed Chair of Anatomy at the University of Valencia, and then known for his histological studies of immunological responses such as inflammation and pus cells[104], Ramón y Cajal was temporally released from his teaching duties to lead the Provincial Government of Zaragoza's efforts to subdue the ongoing cholera outbreak. By then well acquainted with Robert Koch's 1884 report on the discovery of the *Bacillus comma*—the organism responsible for cholera—Ramón y Cajal articulated a series of containment policies while striving to himself isolate the *Bacillus comma* in his home laboratory. On the one hand, Ramón y Cajal's policies aimed to limit the spread of cholera within the population by regulating both bodies and their social contacts. After having tried tactics which specifically targeted individual behaviours, including a failed boil-water order, Ramón y Cajal opted for a more large-scale approach that specifically targeted social interactions. More specifically, Ramón y Cajal's later policies aimed to isolate households from one another by prohibiting members of different family units to eat together, consume food cooked in others' kitchen, or use one another's latrine. On the other hand, Ramón y Cajal's laboratory work strived to reproduce at a microscopic level the type of containment strategies he promoted at a social one by trying to identify which environmental conditions might lead to the bacteria to reproduce more slowly, stagnate, and ultimately lose its

[103] See Santiago Ramón y Cajal, *Investigaciones Experimentales Sobre La Génesis Inflamatoria y En Especial Sobre La Emigración de Los Leucocitos* (Zaragoza, Spain: El Diario Católico, 1880).
[104] Santiago Ramón y Cajal, *Investigaciones Experimentales Sobre La Génesis Inflamatoria* (Zaragoza, Spain: Imprenta El Diario Católico, 1880).

virulence. Exposing various *Bacillus comma* colonies to different conditions ranging from variations in temperature to changing levels of food supply, Ramón y Cajal discovered that colonies exposed to heat gradually reached a state of equilibrium and became inactive enough to be safely inoculated in human subjects.

This work, despite having received little to no attention by the field's main actors at the time, represented Ramón y Cajal's main contribution to bacteriology. In the book that came out of it, Ramón y Cajal provided a comparative study of the *Bacillus comma* in various environments (water, excrement, etc.) and under different conditions (heat, cold, etc.) as well as laid out recommendations for the containment and inoculation of cholera in epidemics-stricken populations[105]. But more importantly, this work initiated a profound experimental shift in Ramón y Cajal's practice, which from that point onward supplemented the minute observation of structures of all kinds with their controlled exposure to various conditions. Beyond the scope of his histological work, this shift also affected his sanitary practice, which came to take as its main object the broader social environment of the populations it targeted. Be it with *Bacillus comma* colonies or cholera-afflicted populations, Ramón y Cajal upheld an experimental approach which consisted in exposing his objects of study to various environmental alterations, study the latter's impact on them, and singled out the best alterations to reach a desired outcome. Away from the type of physiological observations and sanitary measures he had previously promoted, Ramón y Cajal acquired from his experience monitoring, studying, and mitigating the cholera epidemic in Zaragoza a vision of experimentation as applicable to biological and social systems alike, further reaffirming his view of bodies and societies as models for one another.

[105] See Santiago Ramón y Cajal, *Estudios Sobre El Microbio Virgula Del Cólera y Las Inoculaciones Profilácticas* (Zaragoza, Spain: Diputación Provincial de Zaragoza, 1885).

But beyond this experimental shift, Ramón y Cajal's involvement in mitigating the cholera epidemic in Zaragoza also had another key impact on his work—a material one. To reward Ramón y Cajal for his work, the Provincial Government of Zaragoza offered him in 1885 the latest model of Zeiss microscope equipped with a 1.18 immersion objective—"then the last word in magnifying optics"[106]. Far from mundane, this gift not only closed the technical gap between Ramón y Cajal's laboratory and those of Pasteur and Koch, but also allowed him to change the scale of his histological investigations. Compared to traditional ones, immersion objectives allowed to observe structures at an even smaller scale by adding right in front of the objective an immersion liquid with the same refractive index as the glass used for microscope slides. Compared to air, whose refractive index is greater than that of glass, such immersion liquids limited the distortion that otherwise occurred through the refraction of light rays and thus rendered more intricate structures available for observation. Tellingly, it is only then that Ramón y Cajal shifted his attention from the parasites threatening the human body to the body itself and, more specifically, what he referred to as its "central authorities," namely, the nervous system. Gradually shifting his attention from the "periphery" to the "centre" of the body, Ramón y Cajal alternately attended to structures such as bone marrow[107] and the nervous system[108] before making his way to the brain itself[109]. That is not to say that Ramón y Cajal's formulation of neural independence was in any way the straightforward product of his microscopic observations. Instead, it is that his studies of the latter were predicated on his peculiar view of human biology and work in bacteriology, which provided

[106] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 290.
[107] See Santiago Ramón y Cajal, "Notas de Laboratorio: Tejido Óseo y Coloración de Los Cortes de Hueso," *Boletín Médico Valenciano*, 1887.
[108] See Ramón y Cajal, "Estructura de Los Centros Nerviosos de Las Aves."
[109] See Santiago Ramón y Cajal, "Sobre Las Fibras Nerviosas de La Capa Molecular Del Cerebelo," *Revista Trimestral de Histología Normal y Patológica* 2 (1888): 1–17.

the basic language for his introduction of another fundamental structure which, like bacteria, was both discrete and intimately involved in a large web of close interactions—namely, nerve cells.

1.5 "The Elephant's Big Brain": On Neural Independence and Intellectual Superiority

Relieved from public duty in 1886, Ramón y Cajal returned to the University of Valencia to resume his activities as Chair of Anatomy. The subsequent years were characterized by the publication of several anatomical treatises, studies in comparative histology, and technical reports on histological techniques. While his treatises, which combined delicate woodcuts with lyrical reveries on microscopy, were published in local academic journals with the aim of building a Spanish audience for histological research[110], his histological studies were published in German journals for a pan-European audience[111], from which Ramón y Cajal felt unduly excluded[112]. His technical reports, for their part, were specifically written for the small community of Spanish histologists he was part of and focused on the development of staining techniques adapted to the smaller and more intricate structures rendered visible by his new microscope. As one of the structures newly revealed by the latest advances in microscopy, dendrites had by then become an object of sustained investigation and speculations for both Ramón y Cajal and histologists throughout Europe. As he recounted, Ramón y Cajal felt both deeply attracted to "the inscrutable arcanum of the organization of the brain" and frustrated by how it remained "a constellation of

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110 e.g., Santiago Ramón y Cajal, "Notas de Laboratorio: I. Textura de La Fibra Muscular de Los Mamíferos," *Boletín Médico Valenciano*, 1887; Santiago Ramón y Cajal, "Notas de Laboratorio: II. Fibra Muscular Del Ala de Los Insectos," *Boletín Médico Valenciano*, 1887; Santiago Ramón y Cajal, "Notas de Laboratorio: III. Músculos de Las Patas de Los Insectos.," *Boletín Médico Valenciano*, 1887.
111 e.g., Santiago Ramón y Cajal, "Contribution à l'étude Des Cellules Anastomosées Des Épithéliums Pavimenteux Stratifiés," *Internationale Monatsschrift Für Anatomie Und Physiologie* 3, no. 7 (1886); Santiago Ramón y Cajal, "Observations Sur La Texture Des Fibres Musculaires Des Pattes et Des Ailes Des Insectes," *Internationale Monatsschrift Für Anatomie Und Physiologie* 5, no. 6–7 (1888).
112 Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 301–3.

unknowns" in the absence of staining techniques adapted to the scale of brain arborizations[113]. After having experimented with carmine and haematoxylin, which succeeded to some degree in exposing the "initial course of the dendritic processes and nerve fibres"[114], Ramón y Cajal was introduced in 1887 to Golgi's already 15-year-old silver staining technique by a colleague during a short stay in Madrid. Upon his return in Valencia, Ramón y Cajal dedicated the following two years to experimenting with Golgi's technique, which culminated in a series of publications improving on the latter by adding chrome to the silver nitrate solution[115].

Ramón y Cajal's theory of neural independence and, therefore, neural networks model, which he introduced in 18888, cannot be reduced to such technical developments, however. Despite being generally framed in the scientific literature as the direct outcome of contemporaneous improvements in microscopy and histology[116], neural independence was only formally demonstrated in 1955 with the introduction of electron microscopy[117]. Instead, Ramón y Cajal borrowed the notion of neural independence from previous work in embryology, which he conceived of as a useful entry point into the study of a phenomenon that had preoccupied him since his time in Cuba—namely, human development. By the late 1880s, embryologists Wilhelm His and August-Henri Forel had already hypothesized that nerve cells consisted in distinct physiological units based on their studies of the brain's metabolism. In both cases, His and Forel cut off the dendrites connecting various nerve cells together and observed that the latter could survive even when detached from one another. Based on this observation, they hypothesized that

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[113] Ramón y Cajal and Craigie (translator), 305–6.
[114] Ramón y Cajal and Craigie (translator), 304.
[115] e.g., Santiago Ramón y Cajal, "Coloración Por El Método de Golgi de Los Centros Nerviosos de Los Embriones de Pollo," *Gaceta Médica Catalana* 1 (1889).
[116] e.g., Stephen Shepherd, *The Wiley Handbook of Evolutionary Neuroscience* (Chichester, UK: John Wiley & Sons, 2017); Sotelo, "Viewing the Brain through the Master Hand of Ramón y Cajal."
[117] see Sanford Palay and George Palade, "The Fine Structure of Neurons," *Journal of Biophysical and Biochemical Cytology* 1, no. 1 (1955): 69–107.

each nerve cell was fulfilling all the necessary metabolic activities necessary for its survival and thus functioned as independent entities as opposed to a distributed whole[118]. While His and Forel conceived of their theory as a useful explanation for the development of the brain during gestation, Ramón y Cajal for his part adopted the latter as a promising framework to account for the mental and psychological differences he perceived across human populations. For beyond his stated intuition that "anything that concerns unicellular organisms [like bacteria] necessarily applies to nerve cells as well"[119], Ramón y Cajal believed that differences across human groups could only be explained by such a yet-to-be-perceived structure.

As early as 1883, Ramón y Cajal began to wonder how some humans could be "the slave and plaything of cosmic forces [… while others were] the driver of nature and the autocrat of creation"[120]. Throughout the years, this interrogation evolved into a more explicit concern with racial difference and, more specifically, its biological basis, which first took as its object variations in the size of the brain. In the famous Croonian lecture he later delivered to the Royal Society in London, Ramón y Cajal asserted that the way the larger cranium of Africans, such as those he had met during his time in Cuba, correlated with "inferior intelligence if not altogether stupidity"[121] could only be explained by shifting the emphasis away from the sheer size or scale of the brain and its constitutive structures. Just like the "elephant's big brain," Africans' larger cranium was seen by Ramón y Cajal as a sign of underdevelopment and thus of a greater proximity between

[118] see Wilhelm His, "Zur Geschichte Des Menschlichen Rückenmarkes Und Der Nervenwurzeln: Sächsische Akademie Der Wissenschaften Zu Leipzig," *Mathematisch-Physicalische Class* 13 (1886): 477–513; August-Henri Forel, "Einige Hirnanatomische Betrachtungen Und Ergebnisse," *Archiv Für Psychiatrie Und Nervenkrankheiten* 18 (1887): 162–198.
[119] Santiago Ramón y Cajal, *Histologie Du Système Nerveux de l'Homme et Des Vertébrés* (Paris, France: Maloine, 1909), 38–39.
[120] Santiago Ramón y Cajal, "Las Maravillas de La Histología," *La Clínica* 312 (1883): 314.
[121] Santiago Ramón y Cajal, "The Croonian Lecture: La Fine Structure Des Centres Nerveux," *Proceedings of the Royal Society* 55 (1894): 467.

such groups and the “lower mammals [… than] to man”[122]. More specifically, he hypothesized that larger brains were the product of “imperfect connections among nerve cells”[123], whose greater number reflected their poor organization. Based on that, Ramón y Cajal claimed that the richness and complexity—or their lack, thereof—of the connections in the brain was the most probable explanation for “the great differences both quantitative and qualitative in mental capabilities”[124], which at the same time hinted at the functional autonomy of the nerve cells. When Ramón y Cajal claimed that nerve cells were “fully autonomous physiological units”[125], he thus did so as part of a broader attempt to provide a biological explanation for the differences he had perceived among—or rather attributed to—the different populations he had encountered in Cuba.

It is in an article published in 1888 and titled “Estructura de Los Centros Nerviosos de Las Aves,” or “Structure of the Nervous System of Birds,” that Ramón y Cajal first clearly posited his conceptualization of nerve cells as independent units. This article was the first of several publications dedicated to his “new investigations into the nervous system”[126], which he published in the *Revista trimestral de Histología normal y patológica*—a journal founded, and funded, by him—whose 60 copies he personally sent to selected scientists across Europe. In it, Ramón y Cajal explained having exposed to the Golgi’s method “the molecular layer, as well as their nervous prolongations,”[127] of the cerebellum of pigeons, which he had selected for how “certain elements appear more clearly”[128] in the brain of birds than that of mammalians by virtue of its relative simplicity. Providing detailed descriptions of the different types of nerve cells he observed—Purkinje cells, stellate cells, neuroglial cells, etc.—Ramón y Cajal explained how these different

[122] Ramón y Cajal, 467.
[123] Ramón y Cajal, 467.
[124] Ramón y Cajal, 468.
[125] Ramón y Cajal, “Estructura de Los Centros Nerviosos de Las Aves,” 8.
[126] Ramón y Cajal, 1.
[127] Ramón y Cajal, 2.
[128] Ramón y Cajal, 3.

nerve cells were organized into stratified layers, each performing increasingly complex and abstract functions. Looking at the connections across these layers, Ramón y Cajal acknowledged that Golgi's method was "highly inconsistent with relation to the staining of the nervous prolongations" but still claimed that "judging the course and connections of a fiber"' could be achieved "through a comparative study of a great number of good preparations"[129]. Comparing his preparations of bird cerebellums with others he had produced with tissues taken from organisms with increasingly complicated brains—dogs, monkeys, and finally humans—Ramón y Cajal claimed that the structure of the brain was akin to that of biological life itself, growing exponentially more complex yet hierarchically organized with its more sophisticated individuals at the top (see Figure 2). Dismissing the very notion of "diffuse network" as a bygone conception of life, Ramón y Cajal then concluded that the brain was similarly made of distinct and increasingly sophisticated units "interlaced in a very complicated manner […] but never a network"[130].

Following this first piece, Ramón y Cajal published a wide range of articles all featuring detailed drawings of carefully differentiated nerve cells for both a national[131] and an international[132] audience. While initially received with lukewarm enthusiasm by histologists, these articles revived Ramón y Cajal's interest in racial development by providing a tentative explanation for the differences he perceived among human populations. For him, neural independence meant that the brain could develop ever more complex connections, which he

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[129] Ramón y Cajal, 7.
[130] Ramón y Cajal, 8.
[131] e.g., Santiago Ramón y Cajal, "Estructura Del Cerebelo," *Gaceta Médica Catalana*, 1888; Ramón y Cajal, "Coloración Por El Método de Golgi de Los Centros Nerviosos de Los Embriones de Pollo."
[132] e.g., Santiago Ramón y Cajal, "Sur l'origine et La Direction Des Prolongations Nerveuses de La Touche Moléculaire Du Cervelet," *Internationale Monatsschrift Für Anatomie Und Physiologie* 6, no. 4–5 (1889); Santiago Ramón y Cajal, "Sur Les Fibres Nerveuses de La Couche Granuleuse Du Cervelet et Sur l'évolution Des Éléments Cérébelleux," *Internationale Monatsschrift Für Anatomie Und Physiologie* 7, no. 1 (1890).

believed was what had allowed Europeans to be "*the sculptor of [their] own brain*"[133] and acquired their greater intellectual rigour. But far from attributing a similar capacity for intellectual uplifting to all racial groups, Ramón y Cajal specified that some of them were incapable of such mental improvements given how their collective education "began too late" and that the "plasticity of nerve cells [had been] greatly reduced" as a result[134]. But before he expanded his racialized view of neural organization into a broader colonial worldview, which posited that "the same thing happens with the nerve cells as with troops"[135] insofar as they both partake "in the struggle for […] organic evolution"[136], Ramón y Cajal first focused his efforts on demonstrating to the histological community the validity of his theory. To do so, he both developed and deployed a wide range of histological, experimental, and even photographic techniques to construct a structure that had yet to be reified into an object of study—namely, the neuron.

1.6 Communicating the Neuron: From Public Demonstrations to 3-D Photography

Following the publication of "Structure of the Nervous System of Birds," Ramón y Cajal dedicated the subsequent years to promoting his new theory of neuroanatomy throughout the histological community. In 1888 alone, Ramón y Cajal wrote and published a total of nine pieces on neural independence, including two book-length ones each featuring dozens of carefully drawn, discrete nerve cells. But while neuroscientists tend to attribute the widespread adoption of Ramón y Cajal's theory to his use of "monocular microscopes [and …] patience to draw his

[133] Santiago Ramón y Cajal and Neely Swanson (translator), *Advice for a Young Investigator*, 4th ed. (Cambridge, MA: The MIT Press, 1999), xv.
[134] Ramón y Cajal and Swanson (translator), 23.
[135] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 301.
[136] Ramón y Cajal and Craigie (translator), 298.

observations"[137], historians of science have emphasized how the adoption of the neuron doctrine had ultimately little to do with the greater accuracy or precision of the images produced by Ramón y Cajal[138]. As Robert Brain writes, the very meaning of such histological studies was still very much in flux until the turn of the century, as the representation of structures that could only be envisioned after having been exposed to various manipulations and alterations raised the question of how reliable such studies were from both a visual and a physiological standpoint[139]. Even within Ramón y Cajal's entourage, histologists and physicians alike raised concerns about the reliability of his inscriptions. Luis Simarro, for instance, who had been the one to introduce Ramón y Cajal to the Golgi method back in Madrid, wrote to him in 1889 to express that he found his recent work "important […] but not *convincing*" insofar as it "*suggests* rather than *demonstrates*" the structural autonomy of nerve cells[140]. Ultimately, Ramón y Cajal himself grew increasingly unconvinced about how "plates copied from nature with scrupulous care [… could] gain many adherents" [141] to his theory and strived to develop new methods and techniques to render his discrete nerve cells legible as objects of study.

The first of such new methods and techniques, which he called "direct objective demonstration"[142], consisted in exposing his histological preparations in carefully controlled settings where his fellow histologists could observe them under Ramón y Cajal's close supervision.

[137] María Porras and María Báguena, "The Major Discoveries of Santiago Ramón Cajal and His Disciples: Consolidated Milestones for the Neuroscience of the 21st Century," *European Journal of Anatomy* 23, no. 1 (2019): 5; see also Gordon Shepherd, Foundations of the Neuron Doctrine (Oxford, UK: Oxford University Press, 2015).
[138] e.g., Daston and Galison, *Objectivity*; Pratt, *Signs of Science: Literature, Science, and Spanish Modernity Since 1868*; Laura Otis, *Networking: Communicating with Bodies and Machines in the Nineteenth Century* (Ann Arbor, MI: University of Michigan Press, 2001).
[139] Brain, *The Pulse of Modernism: Physiological Aesthetics in Fin-de-Siècle Europe*, 5–36; see also Timothy Lenoir, "Models and Instruments in the Development of Electrophysiology, 1845-1912," *Historical Studies in the Physical and Biological Sciences* 17, no. 1 (1986): 1–54.
[140] Simarro quoted in Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 309f.
[141] Ramón y Cajal and Craigie (translator), 354.
[142] Ramón y Cajal and Craigie (translator), 354.

More specifically, these demonstrations involved Ramón y Cajal travelling with the slides he had previously prepared for his 1888 piece, setting them up in four to seven microscopes at major scientific events, and relating his theory of neural independence to his fellow histologists as they observed his preparations. The value of this method was multiple for Ramón y Cajal, as it allowed to not only do away with the skepticism of many of his peers regarding the reliability of his drawings but also overcome the language barrier that was impinging on the circulation of his ideas. The first of such demonstrations took place at the 1889 congress of the German Anatomical Society. Instead of a talk, Ramón y Cajal requested to be assigned a physical space at the congress, where he laid out "three magnifying instruments [he had requested] besides [his] own excellent Zeiss model"[143]. In them, he placed some of his latest preparations—slices featuring a collage of cerebellum, retina, and spinal cord tissues from bird embryos—and personally showed his preparations to attendees while explaining the neurophysiological properties emerging throughout neural development[144]. While designed with the assumption that "[n]othing convinces like things actually seen"[145], these demonstrations instead centred on inviting participants to enter, and integrate, the very same experimental system that had allowed Ramón y Cajal to capture nerve cells as distinct objects of knowledge in the first place.

Other versions of the same demonstration were later organized in England and the United States, to only name a few, but many historians have emphasized how this first demonstration played a key role in getting Ramón y Cajal's theory to be adopted among most German histologists. As Michael Hanger relates, the 1889 congress of the German Anatomical Society

[143] Ramón y Cajal and Craigie (translator), 355.
[144] In addition to Ramón y Cajal himself, who described this setup in his autobiography, this demonstration is also related by one of the events' most famous attendees—Arthur van Gehuchten—who recalled having been himself the subject of this demonstration. See Arthur van Gehuchten, *Le Névraxe: Recueil de Neurologie Normale et Pathologique, Volume XIV* (Leuven, Belgium: A. Uystpruyst, Éditeur, 1913).
[145] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 354.

provided an unprecedented opportunity for Ramón y Cajal to personally introduce many of the leading figures of histology to his theory of neural independence, which many of them adopted afterward[146]. Among them figured the famous anatomist Heinrich Wilhelm Waldeyer, who subsequently pinpointed the term "neuron" in his 1891 review of Ramón y Cajal's work[147]. Interestingly, it is through these early accounts and translations of Ramón y Cajal's ideas that the notion of network made its way back into Ramón y Cajal's theory and language. In his discussion of the key differences between Golgi's model and that of Ramón y Cajal, for instance, Waldeyer reduced the core of their disagreement to the autonomy of neurons while emphasizing how the fundamental structures they each posited—i.e., continuous fibres and discrete nerve cells—were both "involved in the formation of a network"[148]. While initially met with resistance by Ramón y Cajal, who rejected the figure of the network as too akin "a rigid telegraphic mesh that can neither develop new nodes nor new lines"[149], he ultimately adopted the notion of "multicellular network"[150] and later "neural network"[151] to describe his neuroanatomical model, which informed the means he subsequently developed to both envision, and promote, the latter.

By the turn of the century, Ramón y Cajal's neural networks had become the dominant neuroanatomical model within histological and physiological circles in Spain, Germany, and the United Kingdom, but was still greatly debated in France, Italy, and overseas. In response, Ramón y Cajal strived to develop new techniques that would not only put an end once and for all to the ever-recurring questions about the accuracy of his drawings, but also allow for his theory to travel

146 Michael Hagner, "Les Frères Ennemis de La Physiologie," *Les Cahiers de Science et Vie* 58 (2000): 41–43; see also Otis, *Membranes: Metaphors of Invasion in Nineteenth-Century Literature, Science, and Politics*.
147 See Wilhelm Waldeyer, *Ueber Einige Neuere Forschungen Im Gebiete Der Anatomie Des Centralnervensystems* (Leipzig, Germany: Verlag von Georg Thieme, 1891).
148 Waldeyer, 13.
149 Ramón y Cajal, "The Croonian Lecture: La Fine Structure Des Centres Nerveux," 467.
150 Ramón y Cajal, *Manual de Histología Normal y Técnica Micrográfica*, 225.
151 Ramón y Cajal, "Structure et Connexions Des Neurones," 19.

more freely than his demonstrations could. While skeptical of the scientific value of many of the new instruments that were making their way into many physiological laboratories across Europe, Ramón y Cajal recognized that his neural networks model was bounded to "recent developments in instruments for observation and experiment"[152] and that the latter had a key role to play in "contend[ing] in noble and amicable controversy"[153] like his own. Building on his decades of experience as an amateur photographer, Ramón y Cajal singled out the photographic camera as an instrument uniquely positioned to communicate his neural networks model, should it be endowed with the necessary improvements to not only capture the structural autonomy of individual neurons, but also reveal their profound interconnectedness. Beginning with the development of new gelatin-bromide plates, whose greater sensitivity to contrast allowed him to produce microphotographic studies of optic nerves, Ramón y Cajal from there singled out the refinement of the photographic camera itself as essential to the visualization of neural networks, the gaps among neurons, and the richness of the latter's ramifications.

Ramón y Cajal's first work on photographic techniques can be traced back to a 1904 article on colour photography. While concurrently developed by several scientists and industrialists alike, colour photography was still by the early 1900s an arcane and expensive technique with little to no scientific application[154]. In his piece, however, Ramón y Cajal emphasized the scientific potential of this technology by notably describing different emulsions he had developed to produce colour sensitive plates specifically adapted to the various shades of purple and blue produced by silver staining[155]. Still unable to visualize neural gaps with these improved plates, Ramón y Cajal

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[152] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 364.
[153] Ramón y Cajal and Craigie (translator), 354–55.
[154] see Alicia Faxon, "Intersections of Art and Science to Create Aesthetic Perception: The Problem of Postmodernism," in *The Elusive Synthesis: Aesthetics and Science*, ed. Alfred Tauber (Dordrecht, Netherlands: Kluwer Academic Publishers, 1997), 251–66.
[155] See Santiago Ramón y Cajal, "La Fotografía Cromática de Puntos Coloreados," *La Fotografía* 37 (1904): 5–8.

strived to combine his colour sensitive plates with another type of photographic technique—three-dimensional photography—by building a multi-lens camera designed to simultaneously capture its object at three different focal lengths[156]. Overlapping these three views into a single image, the resulting camera aimed to capture the three-dimensional imbrications among neurons by producing an illusion of depth in the structures it photographed. Further tinkering with the arrangement of lenses by building another camera whose lenses were positioned one next to the other, Ramón y Cajal aimed to emulate human vision by producing photographic diptychs exposing each eye to the same structure from a slightly different angle[157]. Built with the expressed aim of visualizing neural independence, these various plates and cameras camera were actively informed by his neural networks model insofar as their usefulness or accuracy as instruments was measured by their capacity to produce convincing demonstrations of neural independence. In the book which resulted from this work, Ramón y Cajal even concluded that the interpretation of images of neural networks required "a clear understanding of the physico-chemical mechanisms involved in photographic operations"[158]—a statement which, written at the height of Ramón y Cajal's career, collapsed the study of neural networks with the development of new instruments designed to capture them.

Of the many stereoscopic and three-dimensional micrographs that emerged from this work and were published later in various journals, none succeeded at revealing tightly interconnected albeit discrete neurons with the level of detail Ramón y Cajal had hoped for, however. Ramón y Cajal later claimed to have once succeeded at envisioning neural independence by

[156] See Santiago Ramón y Cajal, "Notes Microphotographiques," *Travaux de Laboratoire En Recherche Biologique* 5, no. 1–2 (1907): 23–46.
[157] See Santiago Ramón y Cajal, "Las Placas Autocromas Lumière y El Problema de Las Copias Múltiples," *La Fotografía*, 1907, 9–13.
[158] Santiago Ramón y Cajal, *La Fotografía de Los Colores: Bases Científicas y Reglas Prácticas* (Madrid, Spain: Nicolás Moya, 1912), 7.

"print[ing] successively on a film […] two images" of the same neural structures at slightly different angles and "provid[ing] the spectators with electrical gyratory screens"[159] to create a three-dimensional image but specified that the sheer size and complexity of the equipment involved stopped him from showing it to more than a handful of collaborators. What these various methods and techniques highlight, however, is how neural networks were reified as objects of knowledge through the design of new experimental systems as well as the construction of new instruments specifically built for that purpose. Far from having been popularized and ultimately adopted through minute observations and drawings, neural networks emerged as stable objects of knowledge through the active renegotiation of the practices and tools involved in 19th-century neurophysiological research and anatomy at large. While reliant on the same histological techniques as Golgi's nervous network and reticular theory, Ramón y Cajal's neural networks differed from the latter insofar as they were communicated through complex systems ranging from carefully arranged microscopes featuring purposefully prepared histological studies to projected diptychs observed through electrical gyratory screens in carefully controlled settings. What their adoption ultimately revealed was then not so much their obvious superiority over other models or the greater accuracy of the techniques they involved as a broader transformation of how knowledge about the brain was produced. Far from being straightforward objects of observation let alone of discovery, Ramón y Cajal's neural networks then indexed a broader reordering of neurophysiology both as a field and set of practices—one which captured the brain not so much as an object of observation but as the target of sustained experimental manipulations and technological innovations.

[159] Ramón y Cajal quoted in Juan Fernández Santarén, "Santiago Ramón y Cajal and Three-Dimensional Cinema," *Journal of the History of the Neurosciences* 24 (2015): 118.

1.7 Infecting Neural Networks: Racial Hygiene and Late-Colonial Management

But while the various experimental[160], visual[161], and technological[162] practices associated with turn-of-the-century neurophysiology have already been the object of considerable academic attention, there remains another key area of practice that has rarely been associated with the development of neurophysiology as a field let alone with Ramón y Cajal's work—namely, hygiene and colonial management. In the wake of his work for the Provincial Government of Zaragoza, Ramón y Cajal maintained close links with various government bodies and accepted as a matter of patriotic duty various opportunities to articulate recommendations on the containment of contagious diseases in both continental Spain and its colonies. In the late 1890s, Ramón y Cajal notably took on the role of editor for, and contributor to, a major report on hygienic measures throughout the empire, whose aim was to articulate Spain's first empire-wide sanitation policy. In it, he reintroduced some of the ideas he had previously articulated during his deployment in Cuba. Not only did he emphasize that germs—not insurgents or foreign nations—were the real enemies of Spain in the exercise of its power over its overseas territories, but he also advanced that the same resources and energy that had been previously deployed to conquer these lands should be deployed to eradicate the diseases endemic to them. Emphasizing that "humankind can only guard itself against the enemy that it knows"[163], Ramón y Cajal recommended that the habitats and transmission vectors of these "hidden poisoners"[164] be carefully studied and that empire-wide

[160] Brain, *The Pulse of Modernism: Physiological Aesthetics in Fin-de-Siècle Europe*; see also Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, NJ: Princeton University Press, 1985).
[161] e.g., Crary, *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century*; Daston and Galison, *Objectivity*.
[162] e.g., Ruth Benschop, "What Is a Tachistoscope? Historical Explorations of an Instrument," *Science in Context* 11, no. 1 (1998): 23–50; Catherine Wilson, *The Invisible World: Early Modern Philosophy and the Invention of the Microscope* (Princeton, NJ: Princeton University Press, 1995).
[163] Ramón y Cajal, "Prológo," vii.
[164] Ramón y Cajal, vi.

measures should be implemented to systematically contain, control, and ultimately eradicate them. But in addition to identifying open defecation and stagnant water as key issues, as well as promoting the construction of latrines and the drying up of swamps throughout the empire, Ramón y Cajal also identified local populations as privileged carriers for these diseases. Rehashing the then dominant assumption that some populations were immune to the diseases endemic to their environment[165], Ramón y Cajal emphasized the need for an empire-wide sanitary policy not so much to protect local populations as to prevent local diseases from spreading from the colonies to Spain and thus avoid the contamination of Europeans by foreign bodies.

By the time the report came out in 1901, however, Spain had already lost most of its remaining colonies. In 1898, Spain officially retreated from Cuba and surrendered the Philippines to the United States as a result of the Spanish-American War, the Cuban Revolution, and the Tagalog War. While initially experienced as an illness, amputation, and even "a peril of death"[166] by Ramón y Cajal, these events gradually led him to articulate a new vision of colonial power. Away from the type of "international bullying"[167] of "weaker states [… by] powerful and dominating nations"[168] he had previously promoted, Ramón y Cajal developed a view of the world as made of independent yet irrevocably interconnected nations, whose relationship was based not on domination but on the racial uplifting of one by the other. In place of military power, science and medicine came to stand for Ramón y Cajal as the privileged means through which Spain could not only "enhance its prestige"[169] despite its imperial decline, but also restore close links between itself and its former colonies. Through sanitation, education, and industry, Ramón y Cajal

[165] Ramón y Cajal believed, for instance, that "the negro is almost immune to malaria." See Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 234.
[166] Ramón y Cajal and Craigie (translator), 466–68.
[167] Ramón y Cajal and Craigie (translator), 467f.
[168] Ramón y Cajal and Craigie (translator), 488f.
[169] Ramón y Cajal and Swanson (translator), *Advice for a Young Investigator*, 45.

advanced that Spain could re-emerge as a benevolent force for “humanity and civilization”[170] and develop new connections with its former colonies as well as those of all European nations. In continuity with his neurophysiological work, Ramón y Cajal came to understand the richness of an empire’s links and connections as the main determinant of its advancement and thus perceived the world as akin to a brain in which neurons are tightly interconnected yet organized in a stratified manner. Both from a national and neuroanatomical standpoint, it is a highly expansionist albeit more flexible worldview which Ramón y Cajal came to adopt—one in which the creation of both new connections among neurons and new links among nations was recast as manifestations of the exact same claims for racial superiority.

This latter position is readily expressed by the second landmark report Ramón y Cajal oversaw—i.e., that of the 1910 Commission of the Alfonso XIII National Institute of Hygiene on the sanitary conditions in Spain’s remaining colonial possessions in the Gulf of Guinea. As the founding director of the Institute, which had been created to modernize Spain’s sanitary and healthcare infrastructures as well as carry out advanced bacteriological research[171], Ramón y Cajal had by then become the main advisor of the Spanish government on the control and management of diseases through the empire. Convened at the recommendation of Ramón y Cajal, who wished to turn Spain’s last colony into a testbed for experimental medicine and new hygienic measures, the Commission was specifically mandated to formulate recommendations on how to eradicate the sleeping sickness—an infectious neurological disease endemic to the region, whose debilitating symptoms Ramón y Cajal had come to recognize as one of the main factors explaining the local population’s alleged underdevelopment. For away from his previous conception of racial

[170] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 488f.
[171] See Antonio Lafuente and Tiago Saraiva, “The Urban Scale of Science and the Enlargement of Madrid (1851-1936),” *Social Studies of Science* 34, no. 4 (2004): 554–55.

difference as a biological given, Ramón y Cajal had come to perceive the latter as the product of environmental conditions. No longer interpreted as a sign of local populations' innate backwardness, diseases such as malaria, yellow fever, dysentery, and the sleeping sickness were seen by Ramón y Cajal as the causes for the absence of "any rational exploitation" of the land by the local population as well as for their "languid and lazy life"[172]. By removing these obstacles, however, Ramón y Cajal claimed that these populations could be turned into productive citizens and develop "an agricultural, forest, and livestock industry as prosperous" as that in more advanced colonies[173]. While still evoking local customs, habits, and enduring biological limitations as adverse factors, Ramón y Cajal nevertheless abandoned his previous views about the racial impediments to human development in favour of a vision of racial mobility as something that could be engineered by more advanced nations.

Indeed, this latter view hardly amounted to an explicit critique of his previous ideas about racial difference. After all, Ramón y Cajal's conception of hygiene and human development not only remained very much centred on the idea of race, but also legitimized sustained colonial involvement in both current and former colonies. But what it showed was the gradual translation of previous ideas about race into the framework and language of both hygiene and modern medicine, with various diseases and afflictions becoming stand-ins for certain groups and their perceived backwardness. In the Commission's final report, this conflation was most clearly manifested by the many histological studies of brain tissues it featured. Far from documenting the type of minute neurophysiological differences between Europeans and non-Europeans Ramón y Cajal had previously hypothesized, these studies instead documented the minute degradations of brain tissues taken from deceased local patients infected with the parasite responsible for the

[172] Ramón y Cajal, "Prólogo," 9–10.
[173] Ramón y Cajal, 9.

sleeping sickness. Page after page, the report constructed an image of the native as not only a privileged site of parasitic contamination, but also incapable to fight off such threats on its own. Documenting how African patients failed to consume the arsenical drug atoxyl previously developed to fight the disease with enough consistency as to be effective[174], the report promoted environmental solutions ranging from the clearing out of the bushes where the flies carrying the disease reproduced to the killing of the wild animals susceptible to catching and circulating the disease[175]. Discounting local populations as active actors in these sanitary efforts, the report then proposed to carry an all-out war against the disease, whose occupation of an ever-growing territory reproduced at a microscopic scale Spain's own territorial ambitions on the African continent.

In the name of eradicating local diseases and uplifting the inhabitants of Spain's African colonies, these studies of infected neural networks then characterized local populations as bearers of a profound pathological difference that required no less than the sustained intervention of a foreign power like Spain. Materialized through pictures of brain sections, histological studies of infected brain tissues, and images of both dying and dead patients, neural networks were deployed as a privileged lens to study and identify various diseases and parasites as well as document the pathological difference embodied by those they afflicted. In these later studies, Ramón y Cajal's neural networks emerged as not only a loose inspiration for the organization of nations on a highly interconnected albeit stratified model, but also a powerful rationale to justify the lasting involvement of European nations in the affairs of both their current and former colonies. By reframing local populations as bearers of a profound pathological difference, neural networks were

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[174] The report unsurprisingly avoided all references to the major side effects associated with the drugs, including irreversible blindness. See Dietmar Steverding, "The History of African Trypanosomiasis," *Parasites & Vectors* 1, no. 3 (2008): 4.

[175] See Gustavo Pittaluga, "La Glossina Palpalis En La Colonia Española," in *Informe de La Comisión Del Instituto Nacional de Higiene de Alfonso XIII Enviada a Las Posesiones Españolas Del Golfo de Guinea Para El Estudio de La Enfermedad Del Sueño y de Las Condiciones Sanitarias de La Colonia*, ed. Gustavo Pittaluga (Madrid, Spain: Blass, 1910), 393–402.

made to promote a view of "colonization [as] defensible if not desirable"[176] as long as the latter took the eradication of that difference as its object. Emphasizing that a failure of behalf of Spain to fully eradicate such diseases would amount to no less than "a crime against civilization"[177], Ramón y Cajal thus deployed his neural networks and other histological models as means to reaffirm long-lasting assumptions about racial difference and colonial power under a medical pretense.

Away from its initial introduction as a material explanation for perceived differences between Europeans and the populations they colonized, neural networks' later articulation in the context of Ramón y Cajal's sanitary work then reflected a certain late-colonial model, where the clear domination of a country by another was displaced by appeals to sanitation, racial uplifting, and overall more reciprocal relations across nations—albeit in no less unequal terms. For with his microscopic studies of diseased brains, Ramón y Cajal not only introduced the pathological difference embodied by local patients as a rationale for Spain's renewed presence in Africa, but also emphasized "the threat to the international political order" [178] that the proliferation of such diseases might represent should they make their way into Europe. Noting the increased mobility between Africa and Europe as Spain focused its industrial efforts on its last colony, Ramón y Cajal provided as a justification for his proposed policies that such diseases could one day obliterate European populations if not properly controlled given Europeans' "helpless and defenseless" against such infections, which had been produced by their "comforting and mostly aseptic environment"[179]. In that context, the sanitary and racial hygienic ideas that Ramón y Cajal promoted thus appeared as themselves mirroring the type of relationships that neural networks

[176] Ramón y Cajal, "Prólogo," 13.
[177] Ramón y Cajal, 10.
[178] Ramón y Cajal, 10.
[179] Ramón y Cajal, 9–10.

embodied, insofar as they promoted an understanding of influence across nations and nerve cells alike as not only reciprocal and profoundly distributed in nature, but also in need of purposeful management by its most developed individuals. Indexing a broader shift in Ramón y Cajal's thinking as well as in the colonial doctrine of the Spanish empire, the pathologized brain displaced the racialized one as the privileged object of Ramón y Cajal's neural networks while at the same time reaffirming foreign populations' status as the privileged targets of European interventionism. With his final studies of infected neural networks, Ramón y Cajal thus not only appealed to the regenerative and productive potential of European presence in Africa, but also aimed to create a certain colonial order that would be, in the image of neural networks themselves, more distributed and flexible yet no less stratified and purposefully managed.

1.8 Conclusion

As discussed throughout this chapter, the fundamental problem that neural networks' first iteration was meant to tackle was that of not only providing a clear biological justification to the strict social stratifications underwriting life in Spain's overseas territories, but also developing new links between the Spanish empire and its former colonies. Throughout the second half of the 19th century, these problems constituted some of the most pressing issues faced by Spanish colonial authorities, which were faced with growing anticolonial movements. Joining the medical and later scientific profession at a time that is generally characterized as one of decline in the Spanish empire, Ramón y Cajal became a paradigmatic figure of Spain's shift from a military to a scientific power set on making up for its lost colonies by enhancing its scientific and medical prestige both at home and abroad. While he initially introduced his neural networks model as a way to validate the strict racial hierarchies organizing life in Spain's colonies, Ramón y Cajal later recast his model as a more subtle and flexible one of benevolent influence among nations. Indeed, the continuities between these two iterations are clear: while recast into the language of medicine, contagion, and sanitation, race remained a pillar of Ramón y Cajal's appeal to hygiene and national uplifting, which enabled the regulation of local populations' bodily functions, social contacts, and environmental conditions with the same level of disciplining and intrusion as before. At the same time as they were deployed to settle the problem of how best to understand the brain and its structures, neural networks then also provided a solution to the problem of how to both justify and renew Spain's colonial project by providing a hygienic argument to sustain the profound interdependency between Europe and its colonies both former and current.

But what did change, however, with Ramón y Cajal's later formulations of his neural networks model is the reconceptualization of the brain as the site of not only racial difference, but also pathological difference. If Ramón y Cajal's antagonist, Camillo Golgi, had already promoted such an understanding of the brain in his work on the etiology of mental illness, it is Ramón y Cajal's later studies of infected neural networks that led him to construct the brain as not only an organ prone to disease, but also a privileged object of medical intervention. Anticipating neural networks' later deployment in the field of clinical psychiatry, Ramón y Cajal produced in the last decade of his life various pieces on the neurophysiological basis of dementia[180] and hallucinations[181]. More than race or social status, it is the pathological difference that Ramón y Cajal attributed to certain brains that animated his later work as honorary director of the Alfonso XIII National Institute of Hygiene. In that role, Ramón y Cajal specifically focused on the psychological uplifting of the Spanish population, whose lack of "pedagogical and cultural

[180] e.g., Santiago Ramón y Cajal, "Sur Quelques Lésions Du Cervelet Dans Un Cas de Démence Précoce," *Travaux de Laboratoire En Recherche Biologique* XXIV (1926).
[181] e.g., Santiago Ramón y Cajal, "¿Neuronismo o Reticularismo? Las Pruebas Objectivas de La Unidad Anatomica de Las Celulas Neviosas," *Archivos de Neurobiología* 13 (1933): 219–91.

elevation"[182] he identified as the source of all of the Spanish empire's struggles and decline. When later reinterpreted into a clinical approach to the diagnosis and treatment of mental illness, neural networks carried with them this specific way of conceiving of the brain as malleable but only through external interventions. For despite being abstracted into a model of the mind, neural networks still remained deeply committed to the material structure of the brain and, more specifically, the reducibility of mental states to locatable structures and interactions. Abandoning dead matter and racialized bodies in favour of brain lacerations and psychiatric patients as their privileged model organisms and experimental subjects, neural networks re-emerged by shaping how certain bodies came to be constructed as the bearers of a profound pathological difference requiring yet again a wide range of external interventions and experimental manipulations.

[182] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 558.

CHAPTER 2—UNITED STATES, c. 1927-1969

EMBODYING THE MIND:

ON SIGNALS AND ELECTROSHOCKS

IN MID-CENTURY CLINICAL PSYCHIATRY

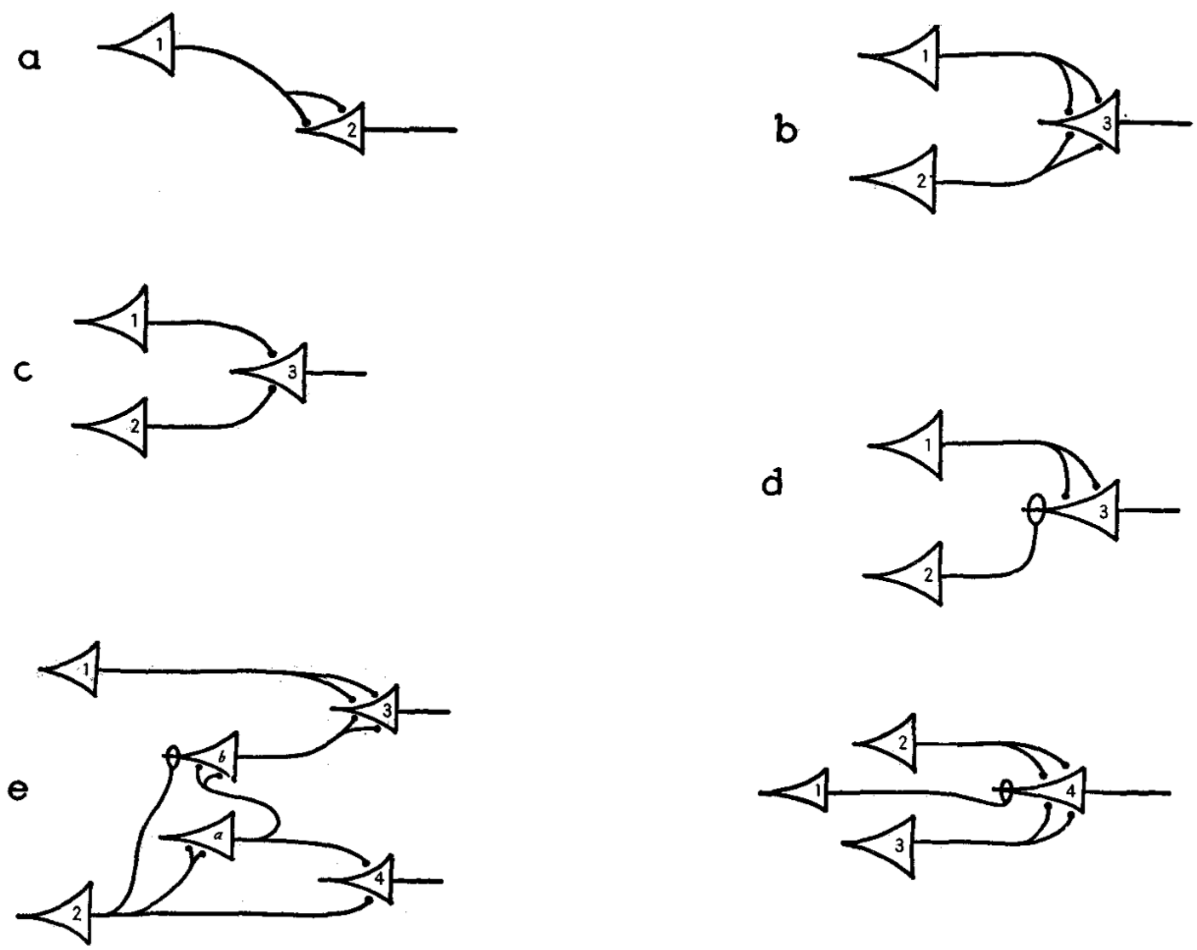

Figure 3. Diagrams of artificial neurons wired together. From McCulloch, Warren and Walter Pitts. “A Logical Calculus of the Ideas Immanent in Nervous Activity.” *Bulletin of Mathematical Biophysics* 5, 1943: p. 130.

2.1 Introduction

Neural networks' second iteration is the usual starting point of most technical and historical accounts of this model. While computer and cognitive scientists attribute to this iteration the original insight that "neural-like networks [can] compute"[183], historians of computing and media theorists for their part tend to recognize in it a first attempt at recasting intelligence in computational terms[184]. In both cases, neural networks are rendered into some sort of logico-mathematical abstraction of intelligence applicable to both brains and computers, which contrasts with the clear clinical scope that animated this model's formulation in the context of mid-century psychiatry. First captured as an object of study through techniques like brain lacerations and strychnine neurography, before guiding clinical trials exploring the use of electroshock therapy on psychiatric patients, neural networks' second iteration indexed both an experimental and a neurophysiological shift in the practice of psychiatry. Introduced as an alternative to psychoanalysis and behaviourism, which then dominated psychiatric institutions in the United States, neural networks aimed to translate in clinical terms Ramón y Cajal's previous work on the biological basis of mental states. Framed as a promising approach for both the diagnosis and treatment of conditions that were considered outside of the realm of intelligibility altogether, neural networks were deployed as a privileged means to recast those unresponsive to psychosomatic treatments into objects of somatic interventions and experimental manipulations. Years before they came to be recognized as the flag bearers of the new "science of signals […] called cybernetics"[185], neural networks were thus first upheld as a model of mental illness, the

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[183] David Rumelhart and David Zipser, "Feature Discovery by Competitive Learning," in *Parallel Distributed Processing, Volume 1*, ed. David Rumelhart and James McClelland (Cambridge, MA: The MIT Press, 1986); Goodfellow, Bengio, and Courville, *Deep Learning*.
[184] e.g., Apprich, "Secret Agents: A Psychoanalytic Critique of Artificial Intelligence and Machine Learning"; Johannes Bruder and Orit Halpern, "Optimal Brain Damage: Theorizing Our Nervous Present," *Culture Machine* 20 (2021): 1–25.
[185] McCulloch and Pfeiffer, "Of Digital Computers Called Brains," 373.

mind, and ultimately knowledge itself through their deployment in both diagnosing and treating some of the newly theorized mental conditions of the 20th century.

This emphasis on neural networks' clinical aspirations is key, as it locates this model's reformulation within the disciplinary and national context of American psychiatry. The history of interwar, wartime, and postwar psychiatry in the United States has been the object of an ever-growing literature since the 1980s, which overwhelmingly characterizes that period as one of upheaval, turmoil, and transformation. Historians of psychiatry generally agree that the control and authority of professional psychiatrists became increasingly undermined from the 1920s onward, with various actors across both disciplines and institutions not only questioning the scientific basis of the field but also recognizing the expertise of other professionals in developing treatment models for psychiatric patients. On the one hand, many scholars have documented the growing influence of neurologists and neurophysiologists on both the conceptualization and treatment of mental illness throughout that period[186]. By proposing to trace back all mental states—and thus illnesses—to locatable structures and well-defined metabolic processes, they raised the prospect of turning psychiatry into a medical practice like any other, which greatly appealed to hospital administrators, philanthropic funders, and policy-makers alike. On the other hand, others have highlighted how actors outside of the medical field came to exert a growing influence on the organization of psychiatric services in interwar America[187]. From lawyers and social workers to sociologists and defence intellectuals, a wide range of new actors became involved in the organization of the psychiatric system, be it by promoting alternative models of care or

[186] See, for instance, Edward Shorter and David Healy, *Shock Therapy: A History of Electroconvulsive Treatment in Mental Illness* (New Brunswick, NJ: Rutgers University Press, 2007), 9–30; Susan Leigh Star, *Regions of the Brain: Brain Research and the Quest for Scientific Certainty* (Stanford, CA: Stanford University Press, 1989), 178–85.
[187] See, for instance, Gerald Grob, *Mental Illness and American Society, 1875-1940* (Princeton, NJ: Princeton University Press, 1983), 30–45; Deborah Weinstein, *The Pathological Family: Postwar America and the Rise of Family Therapy* (Ithaca, NY: Cornell University Press, 2013), 14–46.

emphasizing the environmental aspect of mental illness. And more recently, at the intersection of both literatures, new work has also shed light on the close interplay between ideas about race, class, and gender, on the one hand, and mental illness, on the other, in both pre- and postwar America. By documenting how conditions like neurosis, psychosis, and schizophrenia were disproportionately diagnosed within certain groups[188], these scholars highlight how both shifts contributed to reinscribing within the body of psychiatric patients perceived differences across communities.

Interestingly, none of the scholarship on neural networks has attempted to locate neural networks' re-emergence within this broader context[189]. Be they described as a poetic embodiment of the mind[190] or a biologically inspired model of computation[191], neural networks are generally located with the then-nascent field of cybernetics, with little to no attention being paid to both their articulation and deployment in the context of interwar psychiatry. And yet, it is the very confluence of the various tensions, dynamics, and transformations described above that provided the impetus for neural networks' reformulation into a physiological approach to mental illness by neuropsychiatrist Warren McCulloch (1898-1969). Graduating from Columbia University in 1927 with a medical degree, McCulloch entered the psychiatric practice at a time when the calls for alternatives to institutionalization had given rise to the creation of new outpatient clinics and departments throughout the country. Beginning his career at one of these, McCulloch embraced

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188 See, for instance, Jonathan Metzl, *The Protest Psychosis: How Schizophrenia Became a Black Disease* (Boston, MA: Beacon Press, 2009); Martin Summers, *Madness in the City of Magnificent Intentions: A History of Race and Mental Illness in the Nation's Capital* (Oxford, UK: Oxford University Press, 2019).

189 The only exception to this might be Tara Abraham's critical biography of Warren McCulloch, in which she provides an overview of McCulloch's trajectory across the fields of neurophysiology, psychiatry, cybernetics, and engineering. See Tara Abraham, *Rebel Genius: Warren S. McCulloch's Transdisciplinary Life in Science* (Cambridge, MA: The MIT Press, 2016).

190 Kay, "From Logical Neurons to Poetic Embodiments of Mind: Warren S. McCulloch's Project in Neuroscience," 593.

191 Orit Halpern, *Beautiful Data: A History of Vision and Reason Since 1945* (Durham, NC: Duke University Press, 2014), 169.

neurophysiology as a promising approach to turn psychiatry into a surgery- and drugs-based practice better adapted to the outpatient model. When he later introduced neural networks as a medical rationale for the use of such treatments on psychiatric patients, he did so while running the first clinical trials on electroshock therapy involving patients diagnosed with schizophrenia. Behind McCulloch's seemingly neutral reconceptualization of all mental states as reducible to "the passage of alternating currents through the brain"[192] thus lied a broader concern with not only managing the United States' growing mental health population, but also providing a strong rationale for the subjection of psychiatric populations to increasingly invasive somatic treatments.

To bring these different themes together, this chapter will explore how neural networks' reformulation into a neurophysiological approach to both the diagnosis and treatment of mental illness indexed key changes in both the theory and practice of psychiatry. To do so, it will document the various forms and meanings that neural networks were endowed with, but also the various clinical and experimental practices they both relied on and enabled. First, it will attend to how neural connections came to be experimentally constructed as the fundamental structure underpinning mental illness. Looking into McCulloch's experimental work on cats and monkeys, it will document how neural networks were first captured as an object of clinical intervention through the laceration and poisoning of brain tissues. Second, it will examine not only what type of clinical interventions neural networks provided a rationale for, but also which populations these interventions specifically targeted. By locating McCulloch's clinical trials with patients living schizophrenia within the broader socio-cultural context of wartime psychiatry, it will highlight how neural networks' claims for universalism came to be predicated on this model's capacity to intervene on, and manage, subjects whose condition was deemed beyond comprehension. Finally,

[192] McCulloch and Pfeiffer, "Of Digital Computers Called Brains," 369–70.

it will examine the various tensions underpinning neural networks' reinterpretation into the flag bearer of the new science of communication known as cybernetics. By documenting how the frictions animating the field's own articulation reflected those underpinning neural networks themselves, it will analyze the complex relationship between experimentation and abstraction as it relates to not only neural networks, but also the various fields and settings in which they circulated.

Together, these different sections will highlight how neural networks' second iteration was not so much abstract as experimental, mathematical as clinical, and finally logical as physiological, by recovering the settings, problems, and actors that established the language of what neural networks were and could do. As such, this chapter is then not so much a history of McCulloch or even of neural networks *per se* but of the situated practices, clinical settings, and institutional concerns that shaped neural networks and infused them with some of the meanings they still carry with them today, albeit in a more abstract form. For even more remarkable than neural networks' success at popularizing a new vision of the mind as reducible to locatable structures was the way they recast the psychiatric hospitals of the 20th century into playgrounds for testing new ideas about the mind, reshaping the latter into a privileged object of medical intervention. Even when abstracted into the language of calculus and propositional logic, neural networks continued to carry with them profound assumptions about psychiatric patients' incapacity to be active actors in their own rehabilitation, perpetuating a broader tradition in psychiatry consisting in using psychiatric patients as experimental subjects for the formulation of new theories of the mind[193]. If most accounts of neural networks' history overlook this model's clinical aspirations and experimental

[193] See Bernard Geoghegan, *Code: From Information Theory to French Theory* (Durham, NC: Duke University Press, 2023); Jeffrey Sconce, *The Technical Delusion: Electronics, Power, Insanity* (Durham, NC: Duke University Press, 2019).

component, it might then very well be because of neural networks' own success in abstracting the various managerial techniques they promoted into fundamental principles of neural activities and thus erasing the psychiatric origins of their vision of the mind.

2.2 Locating Mental Illness: On Cross-Region Communication and Brain Lacerations

"What is a number, that a man may know it, and a man, that he may know a number?" This is the question which, in a lecture delivered in 1960[194], Warren McCulloch presented as the fundamental problem addressed by neural networks, a model which he had introduced 17 years earlier. Attributing this question to his 19-year self, who allegedly formulated it when asked by his undergraduate advisor which problem he would like to dedicate his life to, McCulloch claimed that it consisted in the unifying theme of his lifelong attempt "to reduce epistemology to an experimental science"[195]. Relating a career spanning across psychiatry, physiology, cybernetics, engineering, and philosophy, McCulloch presented the study of knowledge's *a priori* conditions as the main thread of his convoluted journey across disciplinary frameworks. This rationale, however, appears as more of a product of McCulloch's sustained efforts to make sense of a decades-long practice across disciplinary boundaries than an actual explanation. First working outside of mainstream psychiatry before joining the ranks of the new field of cybernetics, McCulloch repeatedly reinterpreted his practice as to accommodate the different environments in which he worked. Taking McCulloch's self-fashioning at face value, however, many scholars working on neural networks and their history have focused on such later accounts of McCulloch's model, paying little to no attention to the disciplinary settings in which McCulloch's neural

[194] Originally delivered as the 1960 Alfred Korzybski Memorial Lecture, this text was later published as Warren McCulloch, "What Is a Number, That a Man May Know It, and a Man, That He May Know a Number?," in *Embodiments of Mind*, 2nd ed. (Cambridge, MA: The MIT Press, 1988), 1–18.
[195] McCulloch, 1.

networks were first formulated and deployed. From a simulation of the human brain[196] to a poetic embodiment of the mind[197], from an automation of statistical deduction[198] to a biologically inspired model of computation[199], neural nets have been made into several yet intimately relating things, all representative of McCulloch's ultimate characterization of neural networks as a logico-physiological model of knowledge itself.

But not only do these accounts underplay the rhetorical strategies deployed by McCulloch to produce such coherent narratives[200], but they also altogether overlook the clinical and experimental practices underpinning the formulation of his neural networks model. With McCulloch journeying across various institutional and disciplinary settings, he carried his model with him and reinterpreted it according to each new environment's disciplinary concerns. Instead of a linear evolution, neural networks followed a highly convoluted one, with each articulation both carrying and abandoning some aspects of its previous form. In his own way, McCulloch himself recognized this aspect of his work. In the introduction to his 1959 collection of poems entitled *The Natural Fit*, McCulloch wrote that many characters "have worn the carcass that you see before you," before specifying that "[a]side from an interest in communication they have little in common"[201]. Like McCulloch's many characters, neural networks stood for many things—a biologically inclined approach to clinical treatments, an experimental investigation of the workings of the mind, a mathematical distillation of neural activities, etc.—yet systematically promoted a

[196] Apprich, "Secret Agents: A Psychoanalytic Critique of Artificial Intelligence and Machine Learning," 29.
[197] Kay, "From Logical Neurons to Poetic Embodiments of Mind: Warren S. McCulloch's Project in Neuroscience," 593.
[198] Matteo Pasquinelli, "Machines That Morph Logic: Neural Networks and the Distorted Automation of Intelligence as Statistical Inference," *Glass Bead* 1 (2017): 1.
[199] Halpern, *Beautiful Data: A History of Vision and Reason Since 1945*, 169.
[200] Geoffrey Bowker is one of the few scholars who specifically attended to the rhetorical practices deployed by cyberneticists like McCulloch to universalize their work. See Geoffrey Bowker, "How to Be Universal: Some Cybernetic Strategies, 1943-70," *Social Studies of Science* 23, no. 1 (1993): 107–27.
[201] Warren McCulloch, "The Natural Fit," in *Embodiments of Mind*, 2nd ed. (Cambridge, MA: The MIT Press, 1988), 319.

similar emphasis on communication. Be it in the fields of neurophysiology, psychiatry, cybernetics, or engineering, McCulloch deployed his neural networks as part of a broader attempt to decentre the study of the brain from its formal structure and instead distilling it in terms of electric signals and discrete neural states. While evocative of cybernetics' theoretical commitments, this project then goes back to McCulloch's neurophysiological and psychiatric work throughout the interwar period, when he became part of the growing community of psychiatrists working on the biological basis of mental illness.

When Warren McCulloch began his career as a psychiatrist in 1927, he entered the profession at a time of great turmoil. As Gerald Grob documents, the 1920s witnessed a profound transformation in the organization of psychiatric services, most notably through the creation of outpatient services in both existing hospitals and newly created in-community clinics[202]. In the face of a growing psychiatric population, which spent on average more than five years in institution[203], these new services aimed to provide an alternative to the more resource intensive, inpatient model that then defined the United States' mental health policy. But as these services became adopted across states, and provided the main source of employment for newly trained psychiatrists like McCulloch, they also fuelled the demand for new forms of treatment more adapted to their model. Two distinct approaches to mental illness in particular gained in popularity across these institutions, more specifically by raising the prospect of turning the practice of psychiatry into a dispensary-based one. On the one hand, psychoanalysis and behaviourism emerged as promising approaches to transform psychiatry into a therapeutic practice, which could be broken down into regular sessions with patients. Despite the major conceptual differences among them, these frameworks shared a similar focus on the social, psychological, and

[202] Grob, *Mental Illness and American Society, 1875-1940*, 239–40.
[203] Grob, xii–xiii.

behavioural factors of mental illness and thus promoted psychotherapy as the best line of treatment for psychiatric patients of all kinds. On the other hand, neurology and neurophysiology were also making their way into these new institutions as promising approaches to both the diagnosis and treatment of mental illness. Promoting a vision of mental illness as ultimately reducible to specific brain structures and mechanisms, they conveyed the promise of bringing greater cost effectiveness to clinical treatments by turning psychiatry into a drug- and surgery-based practice.

Following his graduation, McCulloch became affiliated with two institutions closely associated with the latter movement. In 1928, McCulloch joined the Bellevue Hospital in New York City, then already famous for both the size of its outpatient department and cutting-edge experiments with new somatic approaches to mental health treatment[204]. There, in addition to his clinical practice, McCulloch interned at the neurological laboratory of Robert Kennedy, where he worked on the impact of brain injuries on the development of both neurological and psychological disorders. By it through mutilations, provoked hemorrhage, or skull fractures, McCulloch studied the effect of targeted alterations to the brain of cats in the hope of identifying new links between specific brain regions and diseases of all kinds. It is through this research at Kennedy's lab that McCulloch gained his first experience experimenting on living subjects, which evolved into broader physiological affinities that McCulloch later carried with him at the Rockland State Hospital for the Insane. Built in 1926, Rockland was at the forefront of New York State's efforts to accommodate its growing psychiatric population. Situated in the outskirts of New York City, it promoted a hybrid model, in which patients were taken in for nine months before being either assigned for long-term institutional care or to an in-community outpatient clinic. Working at

[204] Bellevue was, for instance, the first hospital in the United States where insulin therapy—an early form of shock therapy that was later replaced by electroshock therapy—was practiced. See Shorter and Healy, *Shock Therapy: A History of Electroconvulsive Treatment in Mental Illness*, 55.

Rockland's Admission Services, McCulloch spent the following two years evaluating where to assign patients at the end of their initial admission, but also researching how this evaluation might be carried more efficiently and rigorously. Focusing more specifically on schizophrenia, which was the diagnosis assigned to most of Rockland's patients, McCulloch tried to identify specific thought patterns that might correlate with the gravity of the faulty brain mechanisms he assumed were responsible for the disease. By the end of this initial six years in the clinical world, McCulloch had then alternatively moved between the disciplinary views of psychiatry and neurophysiology, while ultimately embracing the latter as the basis for a more scientific articulation of the former.

It is then in 1934, when McCulloch secured his first academic appointment at Yale University, that his interest in the neurophysiological basis of mental states translated into a coherent experimental agenda. Joining Yale's Laboratory of Neurophysiology, then headed by experimental physiologist Joannes Dusser de Barenne, McCulloch collaborated with Dusser de Barenne on several experimental studies on the localization of brain functions. Using monkeys as their experimental subjects, they related specific brain functions to individual brain regions, while also documenting the functional relationship across regions. To do so, Dusser de Barenne and McCulloch primarily relied on the injection of strychnine—a powerful neurotoxin with stimulant properties—in brain tissues. After having anaesthetized and carefully exposed the brain of their experimental subjects, they exposed specific regions to strychnine and monitored its effect on their subjects' behaviour. Thanks to its reversible albeit highly stimulant properties, strychnine was seen as an effective alternative to brain lesions by compensating for the depressive effects of surgery. As Dusser de Barenne wrote, subjects "frequently jump[ed] down from the table with all their movements precise and natural" following strychnine exposure, and that, "in spite of undoubted injury to the cortex"[205]. While their experiments centred on demonstrating the existence of functional boundaries between the main brain regions[206], they both rejected any direct correspondence between individual brain functions and specific regions. Instead, they focused on interactions across brain regions by notably attending to how variations in one region correlated with variations in others. In contrast with classical localization theory, which posited a direct relationship between specific brain functions and regions, McCulloch and Dusser de Barenne attended to the functional relationships across regions by monitoring how strychnine exposure in one location affected neural activities in others[207].

As their collaboration evolved, this emphasis on relationships, interactions, and ultimately communication across regions gradually broke away from their initial anatomical efforts. Anticipating McCulloch's later turn to, and formulation of, cybernetics as a science of communication applicable to the study of the brain, their experiments came to centre on how brain regions interacted with one another through what they called "neural pathways." Understood as the neural ramifications connecting brain regions together, neural pathways were captured by Dusser de Barenne and McCulloch as experimental objects through the monitoring and alteration of cross-region communication. In an article entitled "Physiological Delimitation of Neurons in the Central Nervous System," which Dusser de Barenne and McCulloch published in 1939, they

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[205] Johannes Dusser de Barenne, "Experimental Researches on Sensory Localisations in the Cerebral Cortex," *Quarterly Journal of Experimental Physiology* 9 (1916): 358; For a formal description of the strychnine method by McCulloch, see also Johannes Dusser de Barenne and Warren McCulloch, "Some Effects of Local Strychnization on Action Potentials of the Ceberal Cortex of the Monkey," *Transactions of the American Neurological Association* 62 (1936): 171.

[206] See, for instance, Johannes Dusser de Barenne and Warren McCulloch, "Functional Boundaries in the Sensori-Motor Cortex of the Monkey," *Proceedings of the Society for Experimental Biology and Medicine* 35, no. 2 (1936): 329–31.

[207] Johannes Dusser de Barenne and Warren McCulloch, "The Direct Functional Interrelation of Sensory Cortex and Optic Thalamus," *Journal of Neurophysiology* 1, no. 2 (1938): 176–86; Johannes Dusser de Barenne and Warren McCulloch, "Sensorimotor Cortex, Nucleus Caudatus and Thalamus Opticus," *Journal of Neurophysiology* 1, no. 4 (1938): 364–77; Johannes Dusser de Barenne, Warren McCulloch, and Teizo Ogawa, "Functional Organization in the Face-Subdivision of the Sensory Cortex of the Monkey (Macaca Mulatta)," *Journal of Neurophysiology* 1, no. 5 (1938): 436–41.

called the latter method "strychnine neurography"[208] and introduced it as one especially well adapted to mapping neural ramifications. In short, this method consisted in measuring electrophysiological variations in multiple brain regions while exposing a small portion of the brain to strychnine. By documenting how exposure in one region affected—or not—the electrophysiological reading in another, and if such a relation held when the second region was itself stimulated, they built complex models of relations mapping the starting and end points of individual neural pathways across brain regions. Culminating in complex diagrams visualizing the ramifications of each neural pathway involved in specific functions[209], this method contributed to constituting neural pathways as a new fundamental structure that could better account for mental states than brain regions. In that sense, at the heart of their promotion of neural pathways as a new experimental object thus stood a broader experimental reformulation of the field of psychiatry itself, which Dusser de Barenne and McCulloch presented as a more rigorous alternative to the study and treatment of mental illness than the behaviourist and psychoanalytic approaches in vogue at the time.

Before distilling them into complex mathematical abstractions, McCulloch then first engaged with what he later called neural networks as experimentally produced constructions directly inscribed onto brain tissues. Throughout his tenure at Yale, which lasted until 1941, McCulloch's studies of neural pathways combined a reconceptualization of the brain in terms of communication, the experimental alteration of brain tissues, and a broader mistrust of theoretically inclined approaches to human psychology. But despite having no immediate clinical application,

[208] Johannes Dusser de Barenne and Warren McCulloch, "Physiological Delimitation of Neurons in the Central Nervous System," *American Journal of Physiology* 127 (1939): 620.
[209] In this article, for instance, Dusser de Barenne, McCulloch, and High Garol mapped the different neural pathways involved in arm movement across eleven brain regions. See Johannes Dusser de Barenne, Hugh Garol, and Warren McCulloch, "The 'Motor' Cortex of the Chimpanzee," *Journal of Neurophysiology* 4, no. 4 (1941): 287–303.

McCulloch's experiments nevertheless aimed to develop new ways to not only understand, but also treat mental illness. Pursuing these experiments with the intent "of learning enough physiology of man to understand how brains work"[210], McCulloch strived to identify proxies for mental states and phenomena that otherwise seem to be beyond the reach of psychiatric treatment. In line with the then-ongoing reconceptualization of the mind as not only prompt to disease but also a privileged target of medical intervention[211], McCulloch adopted the brain of cats and monkeys as proxies not so much for the human brain as for the diseased mind—a new object of concern that animated both his work and the newly created institutions and services where he worked. Far from being concerned with the brain in and of itself, McCulloch's experiments then manifested a broader commitment to identifying material and structural proxies for various mental illnesses that otherwise seem to be beyond the reach of psychiatric treatment.

McCulloch's peculiar view at the time is best represented by his contemporaneous correspondence with neurosurgeon Percival Bailey, whose lab at the Illinois Neuropsychiatric Institute he later joined. In one letter in particular, McCulloch praised his experiments as the basis for a new physiologically inclined approach to psychiatric treatment, at the same time as he described them as the outcome of a whole new way of conceiving of the relationship between the mind and the brain. Away from the bygone dualism he claimed animated psychoanalysis and other psychosomatic lines of treatment, McCulloch expressed to Bailey that he was "convinced that we will get nowhere with crazy people until we can understand brains in such physio-chemical terms as we use when thinking of kidneys"[212]. Not only did this formulation aim to undermine any clear distinction between the brain and the mind by recasting the former as a proxy for the latter, but it

[210] Warren McCulloch, "Recollections of the Many Sources of Cybernetics," *ASC Forum* 5, no. 16 (1974): 30.
[211] See Grob, *Mental Illness and American Society, 1875-1940*, 108–43.
[212] Warren McCulloch, "Letter to Percival Bailey from 4 February 1941," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 2* (Champaign, IL: University of Illinois Archives, 1941).

also posited that the mind could be ultimately rendered available for psychiatric intervention through the experimental manipulation of the brain. Instead of trying to better understand the mind, McCulloch was thus concerned with the question of how best to intervene on the mind *despite* having limited knowledge about it. McCulloch's project, in that sense, was then not so much an explanatory or descriptive endeavour as a clinical, normative, and predictive one, which reflected psychiatric institutions' concerns with the management of the United States' growing mental health population. Anticipating neural networks' later deployment to theorize and manipulate systems and phenomena that seemed to resist explanation, McCulloch's early work then already manifested a profound concern with the limits of knowledge and, more importantly, how to maintain a certain degree of control over what lied beyond them. By the end of his first experience in the field of neurophysiology, McCulloch had then formulated a highly experimental and structurally inclined view of psychiatry, which provided the basic language underwriting his subsequent attempts to abstract his neural pathways into a model of the mind.

2.3 Differentiating Pathologies: Neural Networks and the "Organically Diseased"

Following Dusser de Barenne's sudden death in 1940, McCulloch concluded his experiments on the brain's functional organization and began his transition away from experimental neurophysiology. Funded by grants awarded to Dusser de Barenne himself, McCulloch's lab was thrown into financial disarray. After months of negotiation with Yale about his appointment as Dusser de Barenne's successor, McCulloch ultimately handed his resignation in August 1941 after having been offered a position as Associate Professor of Psychiatry at the University of Illinois's Illinois Neuropsychiatric Institute (INI). As the product of his ongoing correspondence with Bailey, who personally endorsed his appointment, McCulloch's move signalled a departure from experimental neurophysiology in favour of the field of neuropsychiatry. In an oddly critical obituary for his departed friend, McCulloch distanced himself from experimental physiology by writing that Dusser de Barenne, like most neurophysiologists, was "slow and uncertain of his own reasoning powers"[213]. As he wrote, Dusser de Barenne believed that any argument "was either just words or could be reduced to a question of fact and settled by experiment at once"[214] and as such understood theory as "subservient to experiment"[215]. While indebted to Dusser de Barenne, McCulloch then rejected what he considered as neurophysiology's exaggerated cautiousness vis-à-vis theory and as such transitioned to neuropsychiatry at a moment when his own interest in both the clinical and philosophical implications of neural pathways was becoming increasingly predominant.

As one of the few institutions where fundamental brain research and the clinical treatment of mental health patients coexisted within the same walls, the Illinois Neuropsychiatric Institute (INI) provided a privileged setting for McCulloch to explore the medical application of his research. There, while continuing to further refine his modelling of neural pathways[216], McCulloch focused on the reproduction in experimental subjects of some of the psychiatric diseases he encountered in his clinical practice. Attending primarily to neurosis and psychosis, McCulloch worked on identifying the neural pathways responsible for such pathologies, with the stated intention of identifying new lines of treatment for patients suffering from these conditions. It is also during that period that McCulloch's work simultaneously took on a swift theoretical turn through his meeting and subsequent collaboration with Walter Pitts. As he himself reported,

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[213] Warren McCulloch, "Johannes Gregorius Dusser de Barenne (1885-1940)," *Yale Journal of Biology and Medicine* 12 (1940): 744.
[214] McCulloch, 744.
[215] McCulloch, 744–45.
[216] E.g., Gerhardt von Bonin, Hugh Garol, and Warren McCulloch, "The Functional Organization of the Occipital Lobe," *Biological Symposia* 7 (1942): 164–92.

McCulloch met Pitts, then 16 years old, while participating in the weekly seminars on biophysics held by Nicolas Rashevsky at University of Chicago. Pitts was by then already a protege of Rashevsky, who had a year earlier discerned the potential of this self-taught runaway logician. Recognizing Pitts's interest in logical machines as homologous to his own interest in the brain, McCulloch took Pitts in and raised him along with his other children. There, under McCulloch's mentorship, Pitts applied his knowledge of formal logic to the study of neural activities. Taking McCulloch's neural pathways as his inspiration, Pitts attended not so much to the mechanisms through which neural impulses are transmitted as to the formal relationship among neurons. Positing that the relationships among neurons was equivalent to those among logical propositions, Pitts singled out propositional logic as the optimal lens for representing neural activities, endowing McCulloch's model with new abstract qualities.

But far from being disconnected from one another, McCulloch's clinical and theoretical ambitions directly built off one another. In the first two articles which ensued from their collaboration—articles in which McCulloch's "neural pathways" were renamed "neuron networks"[217] by Pitts—both figures posited that neural organization provided a privileged lens to differentiate between mental conditions that otherwise resisted any clear classification. In May 1942, McCulloch was notably invited by the Josiah Macy Jr. Foundation to present some of their early findings at a conference on the neurophysiological basis of "clinical psychosomatic problems"[218] chaired by the Foundation's director of medical research, Frank Fremont-Smith. In addition to initiating a decades-long collaboration between McCulloch and Fremont-Smith, who

[217] See Walter Pitts, "The Linear Theory of Neuron Networks: The Static Problem," *Bulletin of Mathematical Biophysics* 4, no. 4 (1942): 169–175; Walter Pitts, "Some Observations on the Simple Neuron Circuit," *Bulletin of Mathematical Biophysics* 4, no. 3 (1942): 121–129.
[218] Frank Fremont-Smith, "Letter to Warren McCulloch from April 27, 1942," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 9* (Champaign, IL: University of Illinois Archives, 1942).

became McCulloch's main patron, this meeting introduced McCulloch to the work of Norbert Wiener and Arturo Rosenblueth. At the meeting, Rosenblueth presented an early draft of what later became the well-known piece entitled "Behavior, Purpose and Teleology," which advanced a behavioural approach to the study of complex systems. In his talk, Rosenblueth notably argued that "all purposeful behaviour may be considered to require negative feed-back"[219] and could thus be reduced to questions of communication and information processing. Doing away with historical distinctions between organisms and machines, Rosenblueth claimed that all systems exhibiting purposeful behaviour were subjects to the same control mechanisms and could thus be modelled according not so much to their unique structures and properties as to the functional principles informing their behaviour.

Following the event, McCulloch wrote to Fremont-Smith and expressed how enthralled he was by the lines of inquiry laid out by Rosenblueth—especially given their resonance with his own work. Describing an unnamed, in-progress manuscript he was then writing—most likely the famous "A Logical Calculus"—McCulloch explained being concerned with "the "formal" and "final" aspects of mentality" and thus very much interested in Rosenblueth's ideas vis-à-vis "the dependence of "goal directed" behaviour upon "feed-back" mechanisms"[220]. Feedback, McCulloch claimed, provided a strong rationale for physically rooted theories of the mind, as it anchored its most abstract processes into localized, measurable events. If applied to the study of mental illness, McCulloch wrote, the notion of feedback could be used to not only convert conditions like "neuroses or psychoses into terms of these types of mechanisms," but also treat

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[219] Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow, "Behavior, Purpose, and Teleology," *Philosophy of Science* 10 (1943): 19.
[220] Warren McCulloch, "Letter to Frank Fremont-Smith from June 24, 1942," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 8* (Champaign, IL: University of Illinois Archives, 1942), 1–2.

them "mechanically and physically"[221]. Addressed to one of wartime America's most influential patrons of the medical sciences, this letter and its allusions to clinical applications might indeed have been a pragmatic gesture to secure Fremont-Smith's support. But more broadly it also pointed how the type of logico-mathematical representations of neural activities McCulloch and Pitts produced remained tightly modelled on the mental illnesses McCulloch encountered in his work. More than that, it promoted the psychiatric patients as an ideal figure to conceive of, and model, the brain insofar as they represented a clear deviation from the fundamental principles of neural organization McCulloch and Pitts aimed to capture. However abstract it might be, McCulloch and Pitts's new work then remained concerned with not only distinguishing the many ambiguously differentiated diseases occupying psychiatric institutions, but also developing new ways to treat and manage those diagnosed with them.

In the following months, McCulloch and Pitts finalized and published their now famous paper entitled "A Logical Calculus of the Ideas Immanent in Nervous Activity," which introduced the notion of neural networks to highlight how nervous relations can be represented in terms of functional properties through the use of both formal logic and new ideas about feedback. The piece, however, was originally received with lukewarm enthusiasm. For many of its contemporaries, the piece stood as little but a convoluted exploration of neural activities' logical principles, whose opaque notation and minute neurophysiological details confused psychiatrists and logicians alike. In his review of the piece, Frederic Fitch—one of the article's few reviewers with the necessary training in both psychology and logic to appreciate it—altogether dismissed its use of symbolic logic as employed so "freely and indeed rather carelessly" that it rendered the piece "unnecessarily

[221] McCulloch, 2.

complicated"[222]. For today's commentators, such critiques might indeed seem quite surprising: in both computer and cognitive science, "A Logical Calculus" has itself been used so "freely and indeed rather carelessly" that its initial dismissal as a confusing interdisciplinary experiment provides a stark contrast with the field-defining role it is now endowed with. But beyond the resistance it was initially met with, it is worth unpacking the basic interventions the piece brought forward. For behind its obscure and idiosyncratic system of notation, the piece's intervention more fundamentally consisted in recasting neural activities from a matter of structures and mechanisms to one of discrete states, symbols, and relations. To do so, it relied on Boolean algebra—a type of mathematical logic positing that all logical propositions can be distilled into symbols representing discrete states and types of relation—as its system of notation to model the relationships among neurons. Doing away with the actual mechanisms through which neurons enter an excitatory or inhibitory state, the piece reduced neurons to a discrete value— "on" or "off," "1" or "0"—and modelled the relationship among them in terms of functions such as conjunction, disjunction, and negation. However simple neurons' states and relations were made to be, networks of neurons were nevertheless described as capable of exhibiting exponentially more complex propositions when deployed at a certain scale such as that of the human brain and its 10^{10} neurons. Out of two-state units, McCulloch and Pitts claimed that it was possible to produce any mental process that the human brain is capable of and thus advanced a mechanistic theory of the mind positing that the most complex mental phenomena could still be reduced to networks of otherwise simple units (see Figure 3).

But the core albeit mostly forgotten ambition of their new model remained to reduce mental diseases of all kinds to a clear physical basis and ultimately treat them as physical conditions. In

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[222] Frederic Fitch, "Review of 'A Logical Calculus of the Ideas Immanent in Nervous Activity' by Warren S. McCulloch and Walter Pitts," *The Journal of Symbolic Logic* 9, no. 2 (1944): 49.

their discussion of their model's implications, McCulloch and Pitts steered well away from any metaphorical or universalizing language and instead described their contribution as specifically targeted at both the field and practice of psychiatry. For at the same time as they proposed to distill all mental phenomena into networks of neurons whose relations were equivalent to "those of two-valued logic"[223], they also specified that their model's main purpose consisted in providing an objective lens to distinguish the hysteric from the malingerer, the neurotic from the psychotic as part of their broader project to "diagnose […] the organically diseased"[224]. The choice of these specific conditions as examples of the "organically diseased" is especially telling, as they not only constituted some of the main conditions that (pre)occupied psychiatric institutions throughout the 1940s, but also challenged psychiatry's very capacity to provide meaningful explanations for complex diseases. With McCulloch and Pitts claiming that neural networks demonstrated how "diseased mentality can be understood without loss of scope or rigor, in the scientific terms of neurophysiology"[225], they then introduced their model as a new way to both distinguish and treat diseases that otherwise resisted explanation by reducing them to a stable, biological basis. While implicit to their famous article, these clinical ambitions became especially palpable in their subsequent deployment of neural networks to treat a condition that is especially representative of mid-century psychiatric institution's concern with the diseased mind—namely, schizophrenia.

2.4 Making a Clinical Rationale: On Schizophrenia and Electroshock Therapy

While remembered for its promise to turn the mind into something no longer "more ghostly than a ghost"[226], "A Logical Calculus" then instead first stood as a clinically inclined project

[223] McCulloch and Pitts, "A Logical Calculus of the Ideas Immanent in Nervous Activity," 114.
[224] McCulloch and Pitts, 132.
[225] McCulloch and Pitts, 114.
[226] McCulloch and Pitts, 114.

raising the more practical prospect of providing a new, objective basis for both the identification and treatment of mental illness. The latter prospect was especially attractive to many research administrators of the time including Fremont-Smith from the Macy Foundation, then the leading philanthropic body in medical research in the United States. Less than a month after the piece's publication, Fremont-Smith invited McCulloch to participate in an event dedicated to a condition whose growing prevalence was bringing virtually all psychiatric institutions beyond their bed capacity—namely, war neuroses. Held in January 1944, two years after the United States joined World War II, the event aimed to develop new ways to "use narcosis […] in the treatment of these conditions"[227], providing a privileged setting for McCulloch to promote his neural networks model as a promising framework to relate mental states to the brain's physio-chemical composition. With McCulloch being the only neuropsychiatrist and overall researcher invited by Fremont-Smith, it seems likely that the latter had recognized the potential of neural networks as an actionable framework to conceive of new treatments for both military personnel overseas and afflicted veterans at home. With the affiliations of the other attendees reflecting the growing influence of the military in psychiatric research[228], this event constituted a first instance when McCulloch's neural networks were presented as a potential solution to the growing demand for new lines of treatment that could relieve the growing pressure put on the United States' psychiatric system in the wake of its involvement in the war.

[227] Frank Fremont-Smith, "Letter to Warren McCulloch from January 4, 1944," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 8* (Champaign, IL: University of Illinois Archives, 1944).

[228] A full list of attendees can be found in the McCulloch papers. In addition of representatives from major hospitals, the event primarily featured psychiatrists and military administrators involved in the many new outpatient clinics created outside of urban centres to accommodate the growing number of war veterans coming back to civilian life. See "Members of Conference on the Use of Narcosis and Hypnosis in Psychotherapy of War Neuroses - New York City, Jan. 28-29, 1944," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 8* (Champaign, IL: University of Illinois Archives, 1944).

In addition to setting the stage for McCulloch's later involvement in military research, this event translated into what became a decade-long patronage of McCulloch's work by the Macy Foundation. At the event itself, McCulloch pitched to Fremont-Smith the idea for a research project that would aim to identity the neural mechanisms influencing morale, with the stated aim of developing drugs that could improve the spirits of troops abroad. Fremont-Smith promptly agreed to fund the project[229], which mobilized neural networks as the theoretical basis for linking different moods to specific neural pathways and neurochemical markers. It is, however, McCulloch's second Macy-funded project which first involved conceiving of the brain *as* a neural network, insofar as it proposed to directly intervene on the type of functional relations neural networks reduced the brain to. In the summer of 1944, McCulloch requested the Foundation's support for a multi-year research project dedicated to measuring the impact of electroshock therapy on patients with schizophrenia[230]. While first introduced in the United States in 1939 and already in use in half of psychiatric institutions by the mid-1940s[231], electroshock therapy was devoid of any strong theoretical backing and remained the objects of ongoing debates and controversies among psychiatrists. Collaborating with fellow neuropsychiatrist Ladislas Meduna who, from the 1930s onward, had experimented with other forms of shock therapy, McCulloch framed this endeavour as dedicated to establishing the causes of electroshock therapy's alleged positive impact. Seeing a clear correspondence between the subjection of the brain to electric signals and his reconceptualization of neural activities in terms of signals, McCulloch proposed to use his

[229] Frank Fremont-Smith, "Letter to Warren McCulloch from February 4, 1944," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 8* (Champaign, IL: University of Illinois Archives, 1944).
[230] Warren McCulloch, "Letter to Frank Fremont-Smith from June 13, 1944," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 8* (Champaign, IL: University of Illinois Archives, 1944), 1–2.
[231] Shorter and Healy, *Shock Therapy: A History of Electroconvulsive Treatment in Mental Illness*, 51.

neural networks as a model to both represent what he called the "schizophrenic mind" and monitor its gradual rehabilitation through electroshock therapy.

Formally approved in September 1944[232], this project prompted McCulloch's return to the clinical practice after roughly 10 years of interruption. Carried at the INI, the project brought together a total of twenty-five patients diagnosed with schizophrenia, who were subjected to electroshock therapy three times a week and required to provide both blood and urine samples following each treatment. In default of measuring electrophysiological variations directly into the brain, McCulloch relied on these samples to identify metabolic markers for both short- and long-term neural alterations. After one year of such treatments, McCulloch noted that electroshock therapy had highly uneven effects on schizophrenic patients, with some of them seeing their condition improve while others remained in a similar state of mind. Based on that, McCulloch theorized that what was called schizophrenia consisted in reality in two distinct diseases, each the product of a specific imbalance in the brain's physio-chemical composition. On the one hand, McCulloch speculated that patients who were ""cured" by electric shock" were victims of a faulty neural system, which led them to inadequately process outside information[233]. On the other hand, McCulloch hypothesized that those were unresponsive to it were instead affected by a faulty metabolism altering the good functioning of neural activities and recommended the use of other forms of treatments like insulin therapy or CO_2 poisoning to alter their brain's chemical composition. While ultimately disproved, this distinction highlighted how McCulloch's assumptions vis-à-vis the physical basis of mental illness gave rise to a model of medical diagnosis overly centred on the functional and physical organization of neural activities, to the point of

[232] Frank Fremont-Smith, "Letter to Warren McCulloch from September 22, 1944," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 8* (Champaign, IL: University of Illinois Archives, 1944).
[233] Warren McCulloch, "Letter to Frank Fremont-Smith from June 1, 1948," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 8* (Champaign, IL: University of Illinois Archives, 1948), 1–9.

altogether defining mental conditions based on their receptivity to certain somatic treatments over others. Not only that, but by framing these diseases as deviations from the model of neural organization his neural networks embodied, McCulloch simultaneously deployed his model as a rationale for highly intrusive and violent treatments that directly targeted patients' brains.

But more importantly, it is the choice of patients living with schizophrenia as both the privileged model for, and target of, his neural networks that allows to relate the latter to the broader socio-cultural context of 20th-century psychiatry. As documented in the historical literature, schizophrenia became, and remained, one of psychiatry's defining objects of study for most of the 20th century[234]. At a disciplinary level, schizophrenia stood as the psychopathology *par excellence*, insofar as it represented a seemingly impenetrable mental state that evaded all forms of explanation. For that reason, psychiatrists overwhelmingly defined schizophrenia by what it wasn't rather than by what it was[235]. But beyond the confines of psychiatry, schizophrenia was also widely recognized as a condition representative of the modern experience. In his first comprehensive account of schizophrenia, for instance, Sigmund Freud distinguished the latter from other conditions for the way it "derived from the most general and comprehensible impulses of the human mind"[236]. If the thought structure of patients with schizophrenia was deemed extraordinary, it was for Freud because they couldn't reconcile these impulses with the external world, where changes in, and contradictions between, sexual, religious, and political expectations barred them

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[234] See Erika Dyck, *Psychedelic Psychiatry: LSD from Clinic to Campus* (Baltimore, MD: The Johns Hopkins University Press, 2008); Weinstein, *The Pathological Family: Postwar America and the Rise of Family Therapy*.
[235] As one of McCulloch's contemporaries wrote, schizophrenia was generally understood as the ultimate degree "of disjunction between two persons where the one is sane by common consent." See Ronald Laing, *The Divided Self: An Existential Study in Sanity and Madness* (Baltimore, MD: Penguin, 1962), 36.
[236] Sigmund Freud, "Psycho-Analytic Notes on an Autobiographical Account of a Case of Paranoia (Dementia Paranoides)," in *The Standard Edition of the Complete Psychological Works of Sigmund Freud, Volume XII (1911-1913): The Case of Schreber, Papers on Technique and Other Works* (London, UK: The Hogarth Press, 1958), 18.

from meaningfully locating themselves within their social environment[237]. Back in the United States, as many WWII veterans came back home with paranoia-, hebephrenia-, and catatonia-like symptoms, schizophrenia came to be known as the "the postwar sickness"[238], with returning soldiers being diagnosed *en masse* with this condition. Across disciplines and localities, it was thus as a disease highly representative of the fundamental shifts and tensions underwriting the inter- and postwar periods that schizophrenia came to be conceived of, signalling a broader breakdown of meaning and significance across societies and institutions[239].

McCulloch's own interest in schizophrenia similarly bridged such practical considerations with similar philosophical inclinations. While he noted that his investment in schizophrenia resided in the fact that those it afflicted "occupied half of the mental health beds"[240], he also specified that his understanding of the disease was profoundly indebted to the philosophical work of "Bertrand Russell, Heidegger, Whitehead, and Northrop"[241]. Just as they had attempted to reduce mathematics to logic, McCulloch aspired to do the same with human psychology by distilling both normal and pathological states to a series of (il)logical principles. And yet, McCulloch's career-long interest in schizophrenia also resided in how it supposedly demonstrated the centrality of one of the fundamental mechanisms embodied by neural networks—namely, feedback—whose disruption he considered the source of "schizophrenic oscillations"[242]. Defining the latter

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[237] See Freud, 59–79; see also Eric Santner, *My Own Private Germany: Daniel Paul Schreber's Secret History of Modernity* (Princeton, NJ: Princeton University Press, 1996).
[238] Ellen Herman, *The Romance of American Psychology: Political Culture in the Age of Experts* (Berkeley, CA: University of California Press, 1995), 58.
[239] see Gilles Deleuze and Félix Guattari, *Capitalisme et Schizophrénie: L'Anti-Œdipe* (Paris, France: Les Éditions de Minuit, 1972); Fredric Jameson, *Postmodernism, or, the Cultural Logic of Late Capitalism* (Durham, NC: Duke University Press, 1991).
[240] Warren McCulloch, "Physiological Processes Underlying Psychoneuroses," *Proceedings of the Royal Society of Medicine* 42 (1949): 81.
[241] McCulloch, "What Is a Number, That a Man May Know It, and a Man, That He May Know a Number?," 2.
[242] Warren McCulloch, "Closing Remarks to the 1953 Macy Conference," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 41* (Champaign, IL: University of Illinois Archives, 1953), 2.

mechanism as the process through which "change initiated in some part of the body, including nervous impulses, [… is] stopped or reversed in the part of the body [… that has] given rise to them"[243], McCulloch argued that schizophrenia was but the product of the brain's repeated attempts, and failure, to reverse such changes. Comparing the "schizophrenic mind" to a defective self-steering torpedo, McCulloch emphasized how both systems failed to "readjust subsequent behavior to the outcome of previous behavior so as to minimize its error"[244] and grew increasingly out-of-synch with their aims because of how these errors were iteratively amplified by every attempt to minimize them. Contrarily to other mental conditions, which he understood as produced by illogical relations being embodied in neural connections, schizophrenia stood for McCulloch as a clear manifestation of his model's validity insofar as its underlying causes confirmed that "the notions of feedback are the appropriate ones for the understanding of the normal function"[245] of the brain.

Schizophrenia's privileged status as both deviating from, and reaffirming, the supposedly normal function of the brain indeed reflected its construction as a disease that primarily afflicted a certain class of people not unlike McCulloch himself. In his book on race and schizophrenia in mid-century America, Jonathan Metzl documents how schizophrenia was primarily conceived of as a disease that afflicted white populations and, more specifically, intellectuals up until the 1950s[246]. Even the use of electroshock therapy (ECT) to treat people with schizophrenia was heavily biased toward more affluent patients, as Edward Shorter and David Healy note, who were overwhelmingly "white, middle class, and advantaged"[247]. Even within McCulloch's immediate

[243] McCulloch, 2.
[244] McCulloch, 2.
[245] McCulloch, 3.
[246] Metzl, *The Protest Psychosis: How Schizophrenia Became a Black Disease*, xiii.
[247] Shorter and Healy, *Shock Therapy: A History of Electroconvulsive Treatment in Mental Illness*, 217.

circle, schizophrenia occupied a particular position as a disease that was closely associated with brilliance. By the time their famous 1943 paper came out, Pitts had already experienced several schizophrenic episodes, to which he attributed some of his insights into the logical underpinnings of the mind[248]. But beyond this, it is also as the ideal case study to fulfill his own clinical ambitions vis-à-vis his new model that McCulloch maintained a lifelong interest in schizophrenia. For once considered as the product of faulty feedback mechanisms within the brain, schizophrenia was recast as a disease that could be not only diagnosed based on the physical symptoms associated with these faulty mechanisms, but also treated by physically intervening on the individual organs responsible for the latter. Not unlike his previous attempts to map the relationships between different brain regions via his studies of neural pathways, McCulloch strived to relate schizophrenia to observable physical symptoms and glands, whose close relationship he considered a proof of the neurophysiological basis of mental illness.

There are very few examples of how this use of neural networks to map physical symptoms onto mental conditions specifically unfolded in a clinical setting. Most of the files from McCulloch's trials are either lost or protected, while none of his clinical notes made their way into his otherwise extensive archive. Of the few remaining traces of his clinical practice, however, there is a short correspondence between McCulloch and Dr. Matthew Chappell from Hofstra College, in which Chappell consulted McCulloch on an especially tricky case he had encountered in his clinical practice. In a letter from 1952, Chappell presented to McCulloch the case of a 19-year-old woman who was showing no sign of improvement after more than one year of sustained psychiatric treatment. Daughter to a "highly intelligent [mother]—a Barnard graduate, about forty-five years

[248] see Neil Smalheiser, "Walter Pitts," *Perspectives in Biology and Medicine* 43, no. 2 (2000): 217–26; Elizabeth Wilson, "'Would I Had Him with Me Always': Affects of Longing in Early Artificial Intelligence," *Isis* 100, no. 4 (2009): 839–47.

of age—[…] and a lawyer", the patient had developed auditory hallucinations following the death of her older sister during brain surgery[249]. To Chappell's exhaustive account of her life, which covered aspects ranging from her office job at a watch company to weekly nights out with colleagues, McCulloch singled out Chappell's reference to her skin's sensitivity "to many substances including ordinary soaps"[250] as the only useful information to diagnose her with schizophrenia. Explaining that "changes in skin" correlated with "alterations of threshold and after potentials of neurons"[251], McCulloch hypothesized that Chappell's patient suffered from a deformation of the pituitary gland at the base of her brain, given the latter's role in regulating both skin regeneration and neural activities. As one of the main organs responsible for maintaining homeostasis in the brain, the pituitary gland was for McCulloch the most probable culprit for her condition, as its failure to properly exercise its regulatory functions would also be manifested by skin irritation. Should X-rays confirm that gland's deformation, McCulloch recommended to Chappell to enroll his patient in a CO_2 poisoning treatment—a form of therapy akin to electroshock insofar as it similarly induced an epilepsy-like state in the patient—which would gradually "stimulate [neural] activity and growth of [... the] pituitary"[252].

As this last example illustrates, neural networks remained for McCulloch a highly practical tool to both diagnose and treat some of the main mental conditions treated in postwar psychiatric institutions. Despite their abstract system of notation, neural networks' articulation and promotion as a way to distill mental states into neural signals coincided with their use to not only reconceive of mental diseases as physical ones, but also treat them as such. In McCulloch's clinical trial with

[249] Matthew Chappell, "Letter to Warren McCulloch from March 13, 1952," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 4* (Champaign, IL: University of Illinois Archives, 1952), 1.
[250] Chappell, 1.
[251] Warren McCulloch, "Letter to Matthew Chappell from March 27, 1952," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 4* (Champaign, IL: University of Illinois Archives, 1952), 1.
[252] McCulloch, 1.

patients with schizophrenia, this was manifested by the way neural networks' reconceptualization of the brain in terms of signals legitimized the exposure of dozens of patients to literal electric signals. Deploying his model as a normative framework applicable to perceived pathological difference, McCulloch presented his neural networks as the first of many steps toward an in-depth understanding of "the over-all manifestations of nervous activity whose aberrations are our most vexing problems"[253]. But more practically, neural networks also represented a promising clinical framework to simplify the diagnosis of complex diseases by not only relating mental states to physical ones, but also singling out the individual organs responsible for them as the privileged targets of psychiatric interventions. Describing increased skin sensitivity and even changes in hair thickness as physical manifestations of schizophrenia[254], McCulloch deployed his neural networks a way to develop complex webs of equivalences with the aim of reducing various mental diseases to locatable organs that could be intervened on through treatments such as electroshocks, CO_2 poisoning, and insulin therapy. At the same time as neural networks were deployed to promote a physiologically and biochemically inclined approach to clinical treatment, they were then also themselves both reified and naturalized as a model of the mind through the use of ever more intrusive forms of treatment on psychiatric populations.

2.5 The Cybernetic Mind: Abstraction and Frictions

In the wake of their initial introduction, neural networks thus stood as an experimentally produced model of mental states which not only embodied key assumptions about the "normal" organization of neural activities but also validated itself through the use of highly intrusive forms

[253] Warren McCulloch, "Letter of Recommendation in Support of Walter Pitts' Application to the Guggenheim Memorial Foundation (1945?)," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 19* (Champaign, IL: University of Illinois Archives, 1945), 1–2.
[254] See McCulloch, "Letter to Matthew Chappell from March 27, 1952," 2.

of treatment on psychiatric patients. But despite the support of Fremont-Smith and the Macy Foundation, neural networks received little attention from the psychiatric community. As he wrote in a contemporaneous letter to his friend and colleague Francis Gerty, McCulloch felt ostracized from the rest of the psychiatric community and deplored how his colleagues failed to appreciate the clinical implications of his model[255]. In parallel of his exploration of neural networks' experimental and clinical implications, McCulloch thus supported Pitts's efforts to refine their logical calculus of neural activities as a way to develop new links with other disciplines that might be more receptive to neural networks' materialist underpinnings. To that end, McCulloch notably strived to secure for Pitts academic appointments in leading research institutions where similarly multidisciplinary endeavours were being pursued. At Rosenblueth's invitation, McCulloch wrote to Norbert Wiener in 1944 and requested that Pitts be provided with a research position at the MIT. Already familiar with his work, Wiener gladly accepted Pitts as one of his students and provided him throughout the years with visiting appointments at the Instituto Nacional de Cardiología and Princeton to work with Rosenblueth and John von Neumann. Himself kept in Chicago by his clinical work, McCulloch relied on Pitts to not only expand, but also promote their model beyond the confines of psychiatry, which Pitts did with varying levels of success. Despite being a highly productive period for Pitts, who published follow-up pieces on the logical foundations of neural activities[256], Pitts had a tumultuous relationship with Wiener. From his repeated disappearance while in Mexico to his loss of unpublished manuscripts, to list only two of the many grievances Wiener relayed to McCulloch[257], Pitts gained the reputation of a highly capable yet unreliable

[255] See Warren McCulloch, "Letter to Francis Gerty from November 10, 1943," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 10* (Champaign, IL: University of Illinois Archives, 1943).
[256] See Walter Pitts and Warren McCulloch, "How We Know Universals: The Perception of Auditory and Visual Forms," *The Bulletin of Mathematical Biophysics* 9, no. 3 (1947): 127–47; Walter Pitts and Warren McCulloch, "The Statistical Organization of Nervous Activity," *Biometrics* 4 (1948): 91–99.
[257] See Norbert Wiener, "Letter to Warren McCulloch from April 5, 1947," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 27* (Champaign, IL: University of Illinois Archives, 1947).

collaborator. But before Wiener's irritation with Pitts gave rise to a complete schism between them, Pitts's early collaboration with Wiener contributed to building strong ties between McCulloch and Wiener, who conceived of McCulloch's work as the neurophysiological extension of his own. By 1945, Wiener had become so convinced that McCulloch and Pitts's "very fine ideas on the statistical mechanics of nerve nets" demonstrated that "engineering and neurology [… are] essentially the same"[258] that he expressed to Rosenblueth his intention to solidify these ideas into a permanent research program in collaboration with them.

Despite his reticence vis-à-vis such conflations, McCulloch accepted Wiener's invitation to work together. Their first attempt at scaling their shared interests into a broader research program can be traced back to a conference on negative feedback they organized in 1945 and which featured Wiener as chair and McCulloch as the main keynote. In its themes and format, the conference was presented as a follow-up to the event on cerebral inhibition where McCulloch had first been introduced to Wiener's work and McCulloch dedicated his speakership to laying out the implications of Wiener's modelling of complex systems in terms of their functional properties to the study of the brain. While both men recognized each other as "very slick organizers"[259] and agreed on putting together other events, there remained some fundamental tensions between them with regard to how they each conceived of the meaning and objectives of their new program. Wiener, on the one hand, understood their endeavour as mostly centred on the implications of control mechanisms for both engineering and philosophy. In a letter to Rosenblueth, for instance, Wiener described McCulloch's work as a manifestation of the growing influence of their ideas about feedback across fields, but nevertheless dismissed it as devoid "of serious backing on the

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[258] Norbert Wiener, "Letter to Arturo Rosenblueth from January 24, 1945," in *Norbert Wiener Papers, Box 4, Folder 67* (Cambridge, MA: MIT ArchivesSpace, 1945), 1–2.
[259] Wiener, 1.

medical side"[260]. McCulloch, on the other hand, perceived their program as rooted in the burgeoning field of neuropsychiatry and conceived of it as dedicated to the study of "the formal, logical, or go-no-go aspect […] of nervous activity"[261]. As he wrote to Fremont-Smith, McCulloch imagined that their program would mostly feature physiologists, biochemists, and medical researchers, with only a few "mathematicians and engineering brains"[262] at the periphery.

Before their collaboration had even formally begun, McCulloch and Wiener then already disagreed on the scope and field of application of their new program. If the pragmatics of building a network around this program initially outweighed these frictions, the latter nevertheless remained unresolved for most of their decade-long collaboration. While many accounts of cybernetics' early days recognize the productive role that these uncertainties played in facilitating the circulation of the field's key concepts across fields[263], they still assume that these concepts remained stable across the various fields in which they were "activated"[264]. What the private communications between McCulloch and Wiener hint at, however, is that cybernetics' early years were characterized not so much by such conceptual ambiguities but by clear frictions that ensued from the two distinct agendas with which both figures embarked on this endeavour. In contradistinction with the near-universal science of systems championed by Wiener, McCulloch promoted a vision of a new science that was very much centred on how neural networks could be expanded into a broader model of how thoughts are computed in the brain. Not only that, but his vision also conveyed a strong clinical undertone illustrated by the type of institutional backing he sought for

[260] Wiener, 1.
[261] Warren McCulloch, "Letter to Frank Fremont-Smith from January 23, 1946," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 9* (Champaign, IL: University of Illinois Archives, 1946), 1–2.
[262] McCulloch, 1.
[263] See, for instance, Bowker, "How to Be Universal: Some Cybernetic Strategies, 1943-70"; Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21, no. 1 (1994): 228–66.
[264] See Ronald Kline, *The Cybernetics Moment: Or Why We Call Our Age the Information Age* (Baltimore, MD: Johns Hopkins University Press, 2015).

the events he organized with Wiener. In the first letter he sent to Fremont-Smith on his work with Wiener, for instance, McCulloch described this program as dedicated to the study of how the illogical ideas associated with various psychopathologies could be produced by logical systems like the brain[265].

The notion of friction is key here as it readily captures how McCulloch and Wiener's shared endeavour began not so much as a clear project but as a set of "heterogenous encounters […] leading to new arrangement"[266], to borrow from Anna Tsing's use of the term. In the image of the field's founding proposition, which consisted in linking together seemingly distinct objects based on their shared functional properties, their collaboration reflected "the awkward, unequal, unstable, and creative qualities of interconnection across difference"[267], which arguably contributed as much to the field's appeal as its claims for universalism. The structuring dimension of such frictions is readily captured by their choice of the Macy Foundation as the sponsor for what they conceived of as their new program's inaugural event. Compared to other funding bodies like the Rockefeller Foundation, the Macy Foundation served a fairly well-defined purpose, which consisted in funding "scientific investigations of the fundamental aspects of health, of sickness, and of the methods for the relief of suffering"[268]. From the get-go, Wiener's vision then already contrasted with not only that of McCulloch but also that of their sponsor, whose interest in supporting work on control mechanisms resided solely in its potential application to medical research. Contacted by McCulloch in the very last days of the war, Fremont-Smith saw in the latter's collaboration with Wiener an opportunity to explore how the type of military research Wiener pursued could be

[265] Warren McCulloch, "Letter to Frank Fremont-Smith from August 27, 1945," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 9* (Champaign, IL: University of Illinois Archives, 1945).
[266] Anna Tsing, *Friction: An Ethnography of Global Connection* (Princeton, NJ: Princeton University Press, 2005), 5.
[267] Tsing, 4.
[268] Josiah Macy Jr. Foundation, *Twentieth Anniversary Review of the Josiah Macy Jr. Foundation* (New York, NY: Josiah Macy Jr. Foundation, 1950), 17.

transposed into the framework of civilian medicine[269]. The event proposed by McCulloch and Wiener to the Macy Foundation then ultimately consisted in a key zone of friction between not only neuropsychiatry, mathematics, and electrical engineering but also military and civilian research, itself enabled by the Macy Foundation's interest in finding ways to resolve another key set of frictions: namely, that caused by the return of thousands of soldiers with PTSD, neurosis, psychosis, and schizophrenia back to civilian life[270].

What later came to be colloquially known as the Macy Conferences thus began as an event dedicated to creating new frictions, or "interconnection across difference", between neuropsychiatry, mathematics, and engineering as a way to tackle a pressing social problem faced by psychiatric institutions all around the United States. Officially green-lighted by the Macy Foundation in early 1946, the event and its subsequent editions were perceived by Fremont-Smith as a much-needed alternative to the "social misuse" of science that had characterized World War II. Even more so than McCulloch, Fremont-Smith saw "[t]he failure in communication between disciplines" as the main "problem in every phase of science"[271] and thus promoted interdisciplinarity as a *sine qua non* condition for the development of a new approach to science more attuned to humankind's physical, psychological, and social well-being. Accordingly, Fremont-Smith imposed on McCulloch a requirement for interdisciplinary even greater than the one McCulloch and Wiener had themselves envisioned. To that end, he requested that the programming be developed in collaboration with anthropologist Gregory Bateson, whose work

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[269] See Steve Heims, *The Cybernetics Group* (Cambridge, MA: The MIT Press, 1991), 164–79.
[270] In his introductory remarks to the Macy Conference's sixth edition, Fremont Smith explicitly mentioned the development of more cost-effective treatments to manage the growing population of war veterans in psychiatric institutions as the initial rationale behind its funding of the Macy Conference's first edition. See Frank Fremont-Smith, "Introductory Discussion," in *Cybernetics: Circular, Causal, and Feedback Mechanisms in Biological and Social Systems: Transactions of the Sixth Conference*, ed. Heinz von Foerster (New York, NY: Josiah Macy Jr. Foundation, 1950), 9–26.
[271] Fremont-Smith, 9.

had been previously supported by the Foundation. As one of the few social scientists who were already familiar with the work of both McCulloch and Wiener, Bateson was seen by Fremont-Smith as uniquely positioned to recruit other social scientists who could not only participate in these conversations, but also draw out their sociological implications. Far from diluting the meetings' scope, this inclusion in fact compensated for the reluctance of McCulloch's circles to be part of these conversations. To McCulloch's great disappointment, many of the neurophysiologists and psychiatrists whom he had identified as potential allies turned out to be "not even on speaking terms with inverse feedback"[272]. In retrospect, it seems likely that McCulloch had up until then misjudged the power of attraction among psychiatrists of both his neural networks and Wiener's ideas. Following this setback, McCulloch readjusted his own expectations vis-à-vis these meetings and ultimately proposed to Bateson that their first event's objective be to "make clear the need for theory" to all scholars concerned with human psychology[273].

Held on March 8-9, 1946, the first Macy Conference took place under the name of the "Conference on Feedback Mechanisms and Circular Causal Systems in Biology and the Social Science." In the invitations sent to potential attendees, the event was framed as dedicated to "the mechanisms underlying self-correcting and purposeful behaviour of individuals and of groups"[274]. While the first day succeeded at providing an overview of the latest theories in computing and self-regulating machines, the second failed to productively translate them into a neurophysiological and human framework. As McCulloch himself realized after his own

[272] Francis Bachelard, "Letter to Warren McCulloch from February 14, 1946," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 40* (Champaign, IL: University of Illinois Archives, 1946).
[273] Warren McCulloch, "Letter to Gregory Bateson from February 11, 1946," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 40* (Champaign, IL: University of Illinois Archives, 1946).
[274] Frank Fremont-Smith, "Invitation to the Conference on Feedback Mechanisms and Circular Causal Systems in Biology End the Social Sciences," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 40* (Champaign, IL: University of Illinois Archives, 1946).

presentation on neurons' mechanistic underpinnings, the social scientists, psychologists, and physicians in attendance struggled to make sense of the dense language and mathematical notations used by the mathematicians and engineers, while the former dismissed their peers' work as too specific and ungeneralizable. As mentioned in a note sent by McCulloch to John von Neumann following the event, the type of productive frictions that McCulloch had envisioned had thus failed to materialize, to the point of McCulloch recommending that future editions be divided into two distinct events. While one would be dedicated to further refining the latest theories of complex systems, the other would focus on laying out in more accessible terms these theories' implications for psychologists, psychiatrists, and biologists[275]. Beyond one satellite event on circular causation in human systems held a few months later[276], however, the latter series never materialized and the confusion between the two objectives remained a defining and widely criticized feature of all subsequent Macy Conferences. As a compromise between Wiener's desire to reform the whole of science and McCulloch's investment in promoting his own logico-physiological understanding of human psychology, both figures adopted and promoted an increasingly loose and abstract language which did little to reduce the confusion of most participants. As the editions unfolded, many of the series' most influential participants, like Margaret Mead, Arturo Rosenblueth, and even Pitts, became increasingly vocal about the conference's reliance on vague human-machine metaphors and overall dogmatism, and altogether stopped to attend the series after the first few editions[277].

[275] See Warren McCulloch, "Letter to John von Neumann from February 22, 1946," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 27* (Champaign, IL: University of Illinois Archives, 1946).
[276] Warren McCulloch, "Agenda for the Members of the Conference on Circular Causation - Oct. 17 and 18, 1946," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 40* (Champaign, IL: University of Illinois Archives, 1946).
[277] The McCulloch papers are full of personal communications with core participants of the Macy Conferences in which they expressed their growing disappointment with the series' content and approach. What began with casual excuses—including that the event clashed with "the day of the income tax," as one no-show explained—turned into more overt critiques of the series' idiosyncraticity. A review of the lists of attendees throughout the years highlights how the initial interdisciplinarity of the series gradually gave way to a more dogmatic view, with the conferences being increasingly composed of the main organizers' own students and mentees. Lists of attendees and relevant letters

The undue abstraction which McCulloch was accused of in his network-building efforts, however, worked hand-in-hand with the increasingly empirical understanding of neural networks he developed throughout that period. While first introduced as a physiologically inclined approach to the diagnosis and treatment of mental illness, neural networks gradually evolved into a model of the mind itself, which McCulloch reconceived of as ultimately reducible to the structural qualities of his neural networks. In 1948, McCulloch delivered two lectures in which he described how his model reconciled the fundamental tension between abstraction and empiricism as it relates to not only neural networks' relationship to the mind but also the mind's relationship to the brain. In the first of them, later published under the title of "Why the Mind Is in the Head?," McCulloch acknowledged that the limits of then current techniques forced any theory of the mind to be necessarily speculative in nature, but also defended that all the principles associated with his neural networks model were perfectly coherent with the empirical data available. Of these principles, McCulloch singled out the primacy of neural connections over other structural aspects as the main determinant of mental states as the principle most representative of how generalized models can be built off partial physiological knowledge. While partly speculative in nature, neural networks consisted for McCulloch in a set of useful hypotheses that could be used to inform "an infinite number of experiments" and thus produce new empirical knowledge, even though some of these experiments "are most certain to refute them"[278]. As an inspiration for experimentation, such abstractions thus stood as an empirically rooted, speculative exercise which, as McCulloch claimed in his subsequent lecture titled "Through the Dean of the Metaphysician," was but a necessary evil

can be found in "The Macy Conferences 1946-1955, Box 40," in *Warren S McCulloch Papers, Series No. 35/3/99,* (Champaign, IL: University of Illinois Archives, n.d.).
[278] Warren McCulloch, "Why the Mind Is in the Head?," *Dialectica* 15, no. 9 (1950): 202.

in the absence of complete empirical knowledge. While "abhorred by every man of science"[279], abstractions like neural networks allowed for McCulloch to bridge the gap between epistemology and experimentation and maintained their scientific value as long as they remained committed to the material reality they aimed to capture. While he admitted that it might be impossible to determine if signals and impulses truly are neural activities' fundamental units, he nevertheless emphasized that this conceptualization provided a promising solution to restore causality between the brain and the mind in a way that no other theory had previously succeeded to do[280]. Acknowledging that his neural nets model was indeed "a great heresy"[281], he thus nevertheless concluded that it provided a first, highly necessary step toward transforming epistemology into a full-on experimental project.

By not only recentring the problem of the mind on its material substrate but also rendering that same substrate available for new forms of experimentation, McCulloch's neural networks then consisted in something way more concrete and embodied than the abstract model of the mind[282] or logico-mathematical distillation of neural activities[283] they have been made to be. In many respects, neural networks aimed to recentre the study of the mind on the physical properties underpinning it while at the same time resolving the more fundamental frictions between epistemology and experimentation, abstraction and empiricism. While sympathetic to Wiener's

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[279] Warren McCulloch, "Through the Den of the Metaphysician," *The British Journal for the Philosophy of Science* 5, no. 17 (1954): 19.

[280] McCulloch's disdain for any form of brain-mind dualism is quite clear throughout his work, but his erasure of the body from such considerations is another key pillar of his peculiar view of human psychology. At the same time as his conceptualization of neurons as binary units rendered the brain and the mind as a unified information processing system, it also dismissed the body as a whole as somehow peripheral to the direct, causal relationship between them. See McCulloch, "Why the Mind Is in the Head?," 43–47.

[281] McCulloch, "Through the Den of the Metaphysician," 19.

[282] See Halpern, *Beautiful Data: A History of Vision and Reason Since 1945*.

[283] See Kay, "From Logical Neurons to Poetic Embodiments of Mind: Warren S. McCulloch's Project in Neuroscience."

pursuit of the “widest possible interdisciplinary thinking [… on] communication”[284], McCulloch then nevertheless remained more interested in how such frictions unfolded in highly situated objects like the brain, as opposed to all possible systems at large. When pressed by Wiener to explain how his neural networks model was compatible with the fact that “10^{10} neurons, used as simple relays, are utterly inadequate to account for human abilities”[285], for instance, McCulloch retorted that his work was more interested in how actual neurons process signals than in how whole systems like the brain or computers compute such signals at scale. In contrast with Wiener’s tendency toward abstraction, McCulloch’s first concern then remained with how structures as small and intricate as neural connections could embody logical propositions and resolve any friction between the material and the abstract, in a way science itself had yet to achieve. As a materialistically inclined model of the mind, McCulloch’s neural networks thus also stood as a blueprint for a broader theory of knowledge, which drew inspiration from how the frictions between the material and the abstract were resolved at a biological level in intricate entities like neurons and neural connections.

2.6 From Dissected Frogs to Failing Organs: The Return of the Body

It might very well be this later commitment to the embodied qualities of knowledge that motivated McCulloch’s subsequent, and ultimate, move from the University of Illinois to the MIT. Recruited in 1951 by electrical engineer Jerome Wiesner, the soon-to-be director of the Research Laboratory of Electronics (RLE), McCulloch welcomed this opportunity as a chance to not only

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[284] Warren McCulloch, “Letter to Frank Fremont-Smith from January 8, 1949,” in *Warren S McCulloch Papers, Series No. 35/3/99, Box 40* (Champaign, IL: University of Illinois Archives, 1949).
[285] Heinz von Foerster, ed., *Cybernetics: Circular Causal and Feedback Mechanisms in Biologi- Cal and Social Systems (Transactions of the Sixth Conference, 24-25 March 1949, New York)* (New York, NY: Josiah Macy Jr. Foundation, 1950), 12.

do away with the crushing administrative duties he had at the INI, but also find a more welcoming environment for his studies of neural networks[286]. As he expressed to Wiesner, McCulloch was disheartened by the neuropsychiatric community's enduring resistance to his theories and broader ambition to turn psychiatry into a full-on scientific practice. Enticed by McCulloch's conceptualization of the brain in terms of signals and impulses, Wiesner advocated for McCulloch's hiring by the MIT, which it did in the form of an appointment in its ever-expanding School of Engineering. There, as the founding director of the Neurophysiology Research Group within the Department of Electrical Engineering, McCulloch adopted the tools and vocabulary of information theory, electrical engineering, and communication science in his study of neurophysiology. Concretely, the convergence between these different disciplinary frameworks translated into an experimental agenda focused on finding ways to get neurons and electrical circuits to directly communicate with one another. Assembling a multidisciplinary team composed of neurophysiologists, logicians, and engineers, McCulloch built his lab around the objective of building neural networks using both biological tissues and electrical circuits, which he pursued through the experimental study of information processing in the nervous system.

The main outcomes of McCulloch's first decade at the MIT are best captured by an article titled "What the Frog's Eye Tells the Frog's Brain." While published in 1959, it reflected years of experimentation and technological tinkering pursued by McCulloch in collaboration with his new students. After having developed devices specifically designed to both amplify and monitor neural signals, McCulloch and his team recorded the activities of individual optical fibres during visual stimulation with the aim of modelling the type of information conveyed from the visual apparatus to the visual cortex. Once completed, their experiments suggested that the intensity of nervous and

[286] Warren McCulloch, "Letter to Jerome Wiesner from May 31, 1951," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 28* (Champaign, IL: University of Illinois Archives, 1951).

neural activities correlated not with visual stimulation *tout court* as with the presence of pre-established patterns embedded in nervous and neural connections. Not only did nervous responses correlate with complete visual features like movement, curves, and contrasts, they discovered, but it also turned out the information transmitted by nerves to the brain already aggregated such complex patterns. Concluding that "the eye speaks to the brain in a language already highly organized and interpreted"[287], their paper highlighted how neural connections did not carry raw data but instead complete features and their relations—challenging many of McCulloch's previous assumptions about the logical underpinning of neural activities. After having motivated the pulling apart of frogs' brains, the connection of their nervous systems to sensors and circuits of all kinds, and the exposure of the resulting hybrids to carefully controlled visual inputs, neural nets were then themselves redefined as more probabilistic than logic, more analog than digital. In other words, it is only when McCulloch first actively treated nerves and neurons as electrical circuits that the limits of his conceptualization of the latter in terms of signals and impulses became apparent. In response, McCulloch then proposed to recast his neural networks as a model of how an "infallible network" like the brain can be built out of "fallible neurons"[288], thus shifting the emphasis from localized neural interactions to the brain as a whole.

From a model of cross-region communication in the brain to a logical calculus of neural activities, from a normative approach to psychopathologies to a probabilistic lens to biological systems, neural networks then followed a convoluted path which mirrored McCulloch's own changing priorities and disciplinary commitments. Interestingly, however, none of these articulations reflect neural networks' more recent deployment as a machine learning model. While

[287] Jerome Lettvin et al., "What the Frog's Eye Tells the Frog's Brain," in *Proceedings of the IRE*, vol. 47, 1959, 1950.
[288] Warren McCulloch, "The Reliability of Biological Systems," in *Self-Organnizing Systems: Proceedings of an Interdisciplinary Conference, 5 and 6 May, 1959*, ed. Marshall Yovites and Scott Cameron (Oxford, UK: Pergamon Press, 1960), 268.

regularly referred to in the AI literature as having demonstrated that "neural-like networks could compute"[289], McCulloch had little interest in contemporaneous efforts to develop systems capable to exhibit intelligent behaviour and never paid much attention to contemporaneous efforts to implement his model in computer hardware[290]. At a disciplinary level, his disinterest reflected how the then-nascent field of artificial intelligence was itself defined in opposition to the work of McCulloch and cybernetics at the large. As computer scientist John McCarthy later commented, the very term "artificial intelligence" was in fact originally pinpointed to distinguish the community it encompassed from that of cybernetics on the basis that the "approaches to intelligence" McCarthy and others promoted "were quite different from those advocated by […] Warren McCulloch"[291]. If McCulloch's neural networks anticipated anything about this model's later deployment in the field of machine learning and AI, it might in fact be their highly experimental ethos. Like with McCulloch's own experiments, contemporary neural networks require a high level of involvement from their programmers, who iteratively format their model's training data, alter their model's training parameters, and improve on their model's architecture as they themselves gradually make sense of the tasks and functions at stake.

As the 1960s unfolded, AI gradually overtook cybernetics and neural networks as the dominant framework for the study of both brains and computing machines. Still the head of the RLE's Neurophysiology Research Group, McCulloch became increasingly distant from the day-to-day operations of the lab and gradually adopted the professional persona of an all-around

[289] Rumelhart and Zipser, "Feature Discovery by Competitive Learning"; Hinton and Anderson, "Introduction to the Updated Edition"; Goodfellow, Bengio, and Courville, *Deep Learning*.
[290] See Frank Rosenblatt, "Principles of Neurodynamics: Perceptrons and the Theory of Brain Mechanisms" (Cornell Aeronautical Laboratory, Buffalo, NY, 1961).
[291] John McCarthy, "Review of The Question of Artificial Intelligence: Philosophical and Sociological Perspectives by Brian Boomfield (Ed.)," *Annals of the History of Computing* 10, no. 3 (1988): 225.

philosopher[292]. It is then that McCulloch and Pitts introduced their last—and arguably most lasting—definition of neural networks, which is most succinctly captured by Pitts's last letter to McCulloch. Dated from April 1969, the letter documented in excruciating detail the failings of an entity that had been until then completely overlooked in their study of the brain and the mind, namely, the body as a whole. With both of them sick and bedridden—McCulloch because of a coronary obstruction and Pitts because of a major liver failure linked to his severe alcoholism—Pitts expressed the hope that they should one day "pull [their] wheel chairs together" and discuss one last time Plato's *Protagoras,* "the famous story of the conversation at the house of old Glaucus, where Protagoras and the sophist Hippias were staying"[293]. With great melancholy, Pitts lamented how more than 25 years after the publication of "A Logical Calculus" they were still nowhere close to solving "the paradoxes about the knower and the known"[294] which animated both their work and the famous Platonic dialogue. After decades of silence, the body forced its way into their work through the failings of their own bodies, which became the bearers of the same type of pathological deviance they had for so long attempted to model and intervene on. Anticipating the end of his life, Pitts deplored how their neural networks had opened more questions than they had provided answers to. In a shaky, barely legible handwriting indexing the degradation of his own nervous system, Pitts concluded by asking his lifelong friend and collaborator: Can anything be

[292] In a 1966 letter to Heinz Von Foerster, for instance, McCulloch described his work as increasingly aligned with the fields of philosophy of mathematics and biology. Relating a conference he had just attended at the University of North Carolina, McCulloch mentioned being in conversation with the university's administration for an emeritus cross-appointment in the departments of philosophy and biomathematics following his scheduled retirement from the MIT in 1968. See Warren McCulloch, "Letter to Heinz Von Foerster from December 27, 1966," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 27* (Champaign, IL: University of Illinois Archives, 1966).
[293] Walter Pitts, "Letter to Warren McCulloch from April 21, 1969," in *Warren S McCulloch Papers, Series No. 35/3/99, Box 19* (Champaign, IL: University of Illinois Archives, 1969), 3. The said dialogue was in fact set in the house of Callias, not Claucus.
[294] Pitts, 3.

known about knowledge? If so, how can biological neural networks study, and ultimately know, themselves? If not, can anything be known if the nature of knowledge itself remains a mystery?

The two men never met again, let alone "tr[ied] once more to penetrate these subtle and profound paradoxes"[295]. Pitts died three weeks later from esophageal varices, followed by McCulloch in September 1969. These final questions, however, succinctly captured what can be described as the fundamental *a priori* traversing neural networks' many iterations throughout McCulloch's career. From McCulloch's early experiments on neural pathways to their final articulation as a model of knowledge, neural networks took on several forms that all perpetuated similar assumptions vis-à-vis both the embodied nature of the mind and the empirical basis of knowledge. Against psychosomatic approaches to psychiatry, abstract models of the mind, and symbolic conceptions of artificial intelligence, neural networks were systematically deployed as a promising theoretical framework anchoring the logical underpinnings of the mind into a physical substrate that could be intervened upon. In all these cases, neural networks operated as a discourse-object embodying malleable yet recurrent ideas, which alternately informed how experimental subjects were experimented upon, how conditions like schizophrenia were both defined and clinically managed, and how brains were dissected, altered, and connected onto electrical circuits. In the image of McCulloch's own convoluted journey across experimental neurophysiology, clinical psychiatry, and electrical engineering, neural networks instituted neural activities as the fundamental structure of increasingly abstract phenomena—from mental illness and the mind all the way to knowledge itself—in a way which aimed to provide new means to render these phenomena accessible to experimentation.

[295] Pitts, 3.

Ultimately, however, it is the one thing that neural networks's many iterations and associated practices systematically overlooked—the body—that constituted the main limit to both this model and its creators. While devoid of any clear status in McCulloch's work, the body remained a site of friction resisting the reductionism promoted by neural networks. From the lacerated body of McCulloch's experimental subjects to the electrocuted one of his trials' patients, from the hybridized one of his frogs-turned-electrical-circuits to his own failing body, the body stood as a source of endless complexity and uncertainty, which at the same time inextricably linked neural networks to the various contexts they occupied[296]. Far from a simple oversight, the body's erasure constituted a necessary condition for neural networks' claims for universalism to hold, insofar as its very presence undermined the possibility of reducing complex mental states and phenomena to the neural structures and activities alone. That is not to say that the body was completely absent from McCulloch's work. If anything, it remained an object of sustained interventions, be it through McCulloch's use of brain lacerations, strychnine poisoning, or electroshock therapy in his clinical and experimental work. But for an object so central to McCulloch's experimental and clinical practice, its lack of status points to the way neural networks not only singled out neural structures and activities as the main determinants of mental states, but also obscured all the other structures, organs, and embodied qualities that undermined this generalization. As a model for the embodiments of the mind, neural networks thus stood as a remarkably selective one, which distilled the mind into a handful of physio-chemical properties and reduced the rest of the body into a site of endless frictions that was better left unattended.

[296] see also Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision"; N. Katherine Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Chicago, IL: University of Chicago Press, 1999).

2.7 Conclusion

As discussed throughout this chapter, the fundamental problem to which neural networks' second iteration was designed to tackle what that of how best to not only treat the United States' growing psychiatric population, but also manage conditions which seemed to resist explanation altogether. Throughout both the pre- and postwar periods, these problems constituted some of the main challenges faced by the American medical system and motivated substantial investments in the development of new lines of treatment. Joining the psychiatric profession at such a time of turmoil, McCulloch introduced his neural networks as a more scientifically inclined, and cost-effective, alternative to psychoanalytic and behaviourist approaches to psychiatric treatment, which then dominated psychiatric institutions. By bringing back complex mental states to locatable neural structures, McCulloch's neural networks raised the prospect of turning psychiatry into a surgery- and drugs-based practice, which could be deployed at scale in the many new outpatient clinics built before the war. Taking one of the archetypal figures of mid-century psychiatry—namely, the psychiatric patient with schizophrenia—as both his privileged model and target, McCulloch promoted his neural networks as a rationale for the use of highly intrusive, somatic interventions like electroshock therapy, at the same time as he reconceived of the brain itself as reducible "the passage of alternating currents through the brain"[297]. While eventually expanded into a model of the mind and later knowledge itself, neural networks remained a highly normative construct, whose deployment across fields manifested shared and broader anxieties about deviance, opacity, and unknowability. As a solution to all these problems, neural networks provided locatable and manipulable structures for phenomena both psychological and social that otherwise seemed to evade all scientific intervention—solution which, bridging the disciplinary

[297] McCulloch and Pfeiffer, "Of Digital Computers Called Brains," 369–70.

concerns of psychiatry, neurophysiology, and engineering together, turned the brain into an object of relentless alteration, poisoning, and electrocution.

But far from being limited to neural networks, this overemphasis on the brain characterizes most of the theories of mental illness, the mind, and knowledge of the time, highlighting how both neural networks and the approaches they opposed ultimately inhabited a similar paradigm with regard to the erasure of the body. From somatic to psychosomatic approaches to psychiatry, from neurophysiological to psychoanalytic conceptions of the mind, and even from cybernetic to symbolic models of machine intelligence, all these approaches centred on the same fundamental assumption that "the Mind is in the Head"[298], in McCulloch's works, while paying little to no attention to the body as a whole. This, despite being symptomatic of many strands of research, however, consists in one of the main legacies of neural networks' second iteration, which turned the latter into a necessary condition for the articulation of a theory of mental states, the mind, and ultimately intelligence that could be abstracted beyond the human. When later reinterpreted into a highly operational approach to machine intelligence, neural networks came to not only promote but also generalize a similar disregard for bodies by relocating the intelligence necessary for the completion of complex tasks from the body of individual workers to the structures and organizations they inhabited. Recast into a theory of organization as much as a theory of the mind, neural networks expanded such a careful and standardized manipulation of bodies outside of the realm of clinical psychiatry and into that of labour, government, and organization, to the point of constituting the latter into a prerequisite for both development and deployment of new intelligent machines. No longer inscribed onto individual bodies, neural networks persisted by shaping the

[298] See McCulloch, "Why the Mind Is in the Head?"

organization of large numbers of bodies into their own image, i.e., into tightly interconnected networks of otherwise simple units.

CHAPTER 3—CANADA, c. 1965-2006

MANAGING INTELLIGENCE:

ON NETWORKS AND ORGANIZATION

IN LATE TWENTIETH-CENTURY COMPUTER SCIENCE

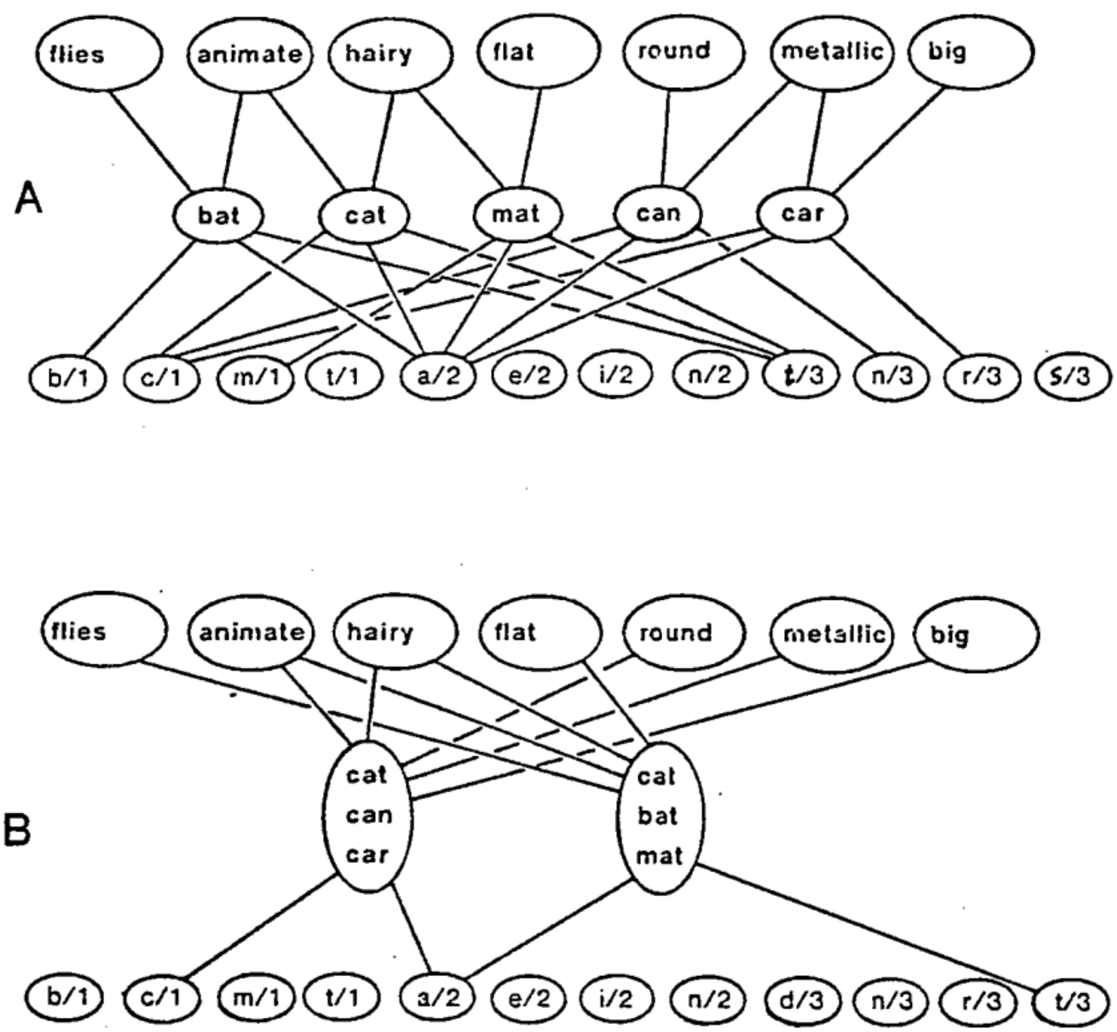

Figure 4. Representation of a three-layer neural network being trained to form sentences using pre-established words. From Geoffrey Hinton, James McClelland, and David Rumelhart, "Distributed Representations," in *Parallel Distributed Processing: Explorations in the Microstructure of Cognition, Volume 1*. Cambridge, MA: The MIT Press, 1986, p. 98.

3.1 Introduction

Neural networks' third and current formulation as a highly operational, statistical approach to artificial intelligence (AI) is the one that comes to mind to most contemporary commentators. As a computationally intensive model reliant on expensive GPUs, large-scale information processing infrastructures, and extensive databases, neural networks have been studied from a wide range of angles, including that of the natural resources they consume[299], the human labour they involve[300], and the reconceptualization of all things into potential data sources they foster[301]. Taken together, these different interventions all point to how neural networks' current iteration functions as something other than the data processing, number crushing technology it is made to be by its developers and promoters alike. To operate, neural networks rely on the careful management of huge amounts of resources, people, and data on a highly distributed albeit purposefully managed model, which itself mirrors their distributed architecture and purposeful training. Far from peripheral, this managerial component not only reflects how neural networks primarily function as an organizational technology, but also mirrors how their re-articulation into an AI model was precisely driven by renewed concerns with organization. For when various government institutions, funding bodies, and research agencies adopted neural networks as a promising approach to develop computer systems capable to fulfill operationally relevant tasks in the 1980s, they did so on the backdrop of a broader vision of networks as an ideal model to organize their own workforce and resources. In the image of neural networks, which theorized how simple components can be made to perform tasks exponentially more complex than themselves, the notion

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[299] e.g., Mél Hogan, "Data Flows and Water Woes," *Big Data & Society* 2, no. 2 (2015): 1–12; Anne Pasek, "Managing Carbon and Data Flows: Fungible Forms of Mediation in the Cloud," *Culture Machine* 18 (2019): 1–15.
[300] e.g., Neda Atanasoski and Kalindi Vora, *Surrogate Humanity: Race, Robots, and the Politics of Technological Futures* (Durham, NC: Duke University Press, 2019); Jennifer Rhee, *The Robotic Imaginary: The Human and the Price of Dehumanized Labor* (Minneapolis, MN: University of Minnesota Press, 2018).
[301] e.g., Kate Crawford, *Atlas of AI: Power, Politics, and the Planetary Costs of Artificial Intelligence* (New Haven, CT: Yale University Press, 2021); Ricaurte, "Data Epistemologies, The Coloniality of Power, and Resistance."

of network provided a promising framework to organize scattered resources, scarce human skills, and at times opposing interests towards desired ends. Before they would raise the prospect of full-on automation, it was thus the goals of optimizing limited resources, enhancing existing processes, and creating new networks that neural networks embodied.

This emphasis on neural networks' deployment as an organizational technology is key to historicize their promotion by many governments around the world as a national imperative[302]. In recent years, several scholars have attended to the interplay between postwar ideas about computing, systems, and networks, on the one hand, and new models of government organization, on the other one. In conversation with previous works on the transformative effect of cybernetic ideas on Soviet and American social science[303], these scholars addressed how notions like "systems," "networks," and "machines" were adopted as powerful categories to not only model entities like "population," "the economy," or "labour forces," but also develop policies and mechanisms designed to manage and control them. While Hunter Crowther-Heyck highlighted how techno-cultural ideas about systems and organization came to "inform and validate policy decisions both large and small"[304] in Cold War United States, Eglė Rindzevičiūtė for her part documented the transnational adoption of systems and network theory as "a source of avant-garde ideas on governability" [305]. Covering national settings as diverse as the United States[306], the United

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302 see Jascha Bareis and Christian Katzenbach, "Talking AI into Being: The Narratives and Imaginaries of National AI Strategies and Their Performative Politics," *Science, Technology, & Human Values*, 2021, 1–27.
303 e.g., Slava Gerovitch, *From Newspeak to Cyberspeak: A History of Soviet Cybernetics* (Cambridge, MA: The MIT Press, 2002); Kline, *The Cybernetics Moment: Or Why We Call Our Age the Information Age*; Mark Solovey, "Cold War Social Science: Specter, Reality, or Useful Concept?," in *Cold War Social Science: Knowledge Production, Liberal Democracy, and Human Nature*, ed. Mark Solovey and Hamilton Cravens (New York, NY: Palgrave Macmillan, 2012), 1–23.
304 Hunter Crowther-Heyck, *Age of System: Understanding the Development of Modern Social Science* (Baltimore, MD: Johns Hopkins University Press, 2015), 8.
305 Eglė Rindzevičiūtė, *The Power of Systems: How Policy Sciences Opened Up the Cold War World* (Ithaca, NY: Cornell University Press, 2016), 6.
306 Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America*.

Kingdom[307], Chile[308], and more recently China[309], this literature related the gradual reconceptualization of government in terms of structures and organization from the 1950s onward, with the optimal management of complex social systems being recognized as the ultimate end of government. If this assessment still resonates today, it is partly because these theoretical lenses and disciplinary reforms continue to animate contemporary ideas about AI[310], whose reliance on the systems thinking and managerial literature of the 1970s and 1980s hints at a certain nostalgia for structuralist and organizational conceptions of the government.

Despite its status as a world leader in the field of AI[311], however, none of this work has attended to the Canadian context specifically. As a second-tier industrialized nation whose research policy has been historically tied to that of the United Kingdom and, later, the United States, Canada occupies as a peripheral role in the history of science and technology. And yet, it is there that neural networks' third and current iteration emerged thanks to the sustained support of Canadian federal institutions, which provided both the funding and the opportunities to test and implement new applications for this model. From 1986 onward, it is the newly created Canadian Institute for Advanced Research that provided Geoffrey Hinton, the so-called "Godfather of AI"[312], with the necessary support to research applications for neural networks. In the process, he gradually recast them from an abstract model of mental states to a highly operational approach to

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307 Andrew Pickering, *The Cybernetic Brain: Sketches of Another Future* (Chicago, IL: University of Chicago Press, 2010).
308 Eden Medina, *Cybernetic Revolutionaries: Technology and Politics in Allende's Chile* (Cambridge, MA: The MIT Press, 2011).
309 Xiao Liu, *Information Fantasies: Precarious Mediation in Postsocialist China* (Minneapolis, MN: University of Minnesota Press, 2019).
310 see Benjamin Peters, *How Not to Network a Nation: The Uneasy History of the Soviet Internet* (Cambridge, MA: The MIT Press, 2016), 17–24.
311 see Tim Dutton, Brent Barron, and Gaga Boskovic, *Building an AI World: Report on National and Regional AI Strategies* (Toronto, Canada: Canadian Institute for Advanced Research, 2018).
312 Association for Computing Machinery, "Fathers of the Deep Learning Revolution Receive ACM A.M. Turing Award: Bengio, Hinton and LeCun Ushered in Major Breakthroughs in Artificial Intelligence," *Press Release*, 2018.

machine intelligence. As the most quoted scholar in the field of artificial intelligence, Hinton is generally recognized by both practitioners[313] and historians[314] as the one person who, after their fall from grace in the late 1960s[315], single-handedly reintroduced neural networks as a way to train computers to perform complex tasks in a semi-autonomous manner. Working against the hard-coded rules and heuristics that then characterized the field, he introduced a novel way to both define and operationalize machine intelligence, which predicated the latter on computer systems' capacity to perform operationally relevant functions. Taking as his earliest use cases minute tasks relevant to the various federal institutions supporting his work, Hinton made his model legible as an approach to AI at the same time as he raised the prospect of using it to reintroduce a certain level of top-down oversight over the ever-growing federal bureaucratic machine.

For far from accidental or anecdotal to their development, the Canadian institutional context provided a privileged backdrop for neural networks' re-articulation into both an operational approach to machine intelligence and an organizational technology. From the 1950s onward, federal administrators and politicians alike all strived to develop new ways to restore oversight over the ever-expanding Canadian civil service, by notably trying to create a new type of civil servant. Seen as smart yet capricious, well educated albeit too individually minded, the postwar civil servant was recast into a threat to the type of government-wide reforms and ambitious policies that the Canadian state required to both strive economically and survive politically. For federal administrators, this model had to be replaced by a new civil servant, who would be mostly untrained and easily replaceable yet capable of performing complex tasks given the right tools,

[313] Goodfellow, Bengio, and Courville, *Deep Learning*.
[314] e.g., Dominique Cardon, Jean-Philippe Cointet, and Antoine Mazières, "Neurons Spike Back: The Invention of Inductive Machines and the Artificial Intelligence Controversy," *Réseaux* 211 (2018): 173–220.
[315] see Marvin Minsky and Seymour Papert, *Perceptrons: An Introduction to Computational Geometry* (Cambridge, MA: The MIT Press, 1969).

structures, and overall organization. Among other things, this position translated into a series of applied research programs that not only aimed to reduce the government's reliance on skilled labour, but also established the government clerk as both the target and the model for the development of new intelligent machines. Starting with its landmark machine translation program (1965-1972), the federal government adopted computing research as a natural area of government responsibility insofar as it could be used to break down complex tasks into highly standardized ones, which could then be fulfilled by untrained workers. From that point onward, computing emerged, and remained, an enduring site of political investment and speculation, where the prospect of machine intelligence came to be raised alongside that of improved managerial practices and centralized decision-making, motivating a wide range of targeted investments and government reforms throughout the second half of the twentieth century. As such, when (re)introduced, Hinton's neural networks culminated close to 30 years of government-led experiments in both computing research and government organization, whose aim consisted in bringing government clerks back under control.

To bring these different themes together, this chapter will relate the re-emergence of neural networks as a technology designed to manage and organize labour to the Canadian state's postwar concerns with organization, management, and national unity. To do so, it will document the development within the Canadian federal government of a more expansive understanding of networks as not only a highly operational approach to machine intelligence, but also the ideal model to carry that type of work. First, it will attend to the articulation of communication and, later, computing technologies as privileged means to tackle key problems faced by the Canadian state. Looking into how Canada's very "existence as an economic unit" came to be understood as "predicated upon […] communication technology,"[316] this chapter will argue that the federal government's perceived responsibility to regulate communication networks translated into a broader reconceptualization of both Canada and its government as themselves akin to communication networks. Second, it will examine how the computer came to be seen as a privileged tool to govern such a networked country as well as restore control over an entity as large and distributed as the Government of Canada. Documenting how the federal government's first programs in computing research all aimed to break down complex operations into standardized tasks that could be performed by computer-aided workers, this chapter will argue that the notion of network came to represent a new way of organizing and managing human labour on a distributed yet purposefully managed model. Third, it will examine how these programs, reforms, and ideas about government provided the language for what neural networks were and could do. Documenting the evolution of Geoffrey Hinton's work and ideas from his arrival in Canada all the way to his appointment as the director of the Canadian Institute for Advanced Research's AI program, it will argue that neural networks' changing meaning and functions indexed a broader reconceptualization of organization, management, and government in late 20th-century Canada.

Together, these different sections will support an understanding of government and technology as tightly intertwined with one another. As this institutional history of neural networks will show, this proximity is not only material but also conceptual, insofar as the re-emergence of neural networks both benefitted from sustained government support and provided a powerful analogy to validate new models of government. One the one hand, this history highlights how governments like that of Canada play a key role in shaping the development of new technologies.

[316] Maurice Charland, "Technological Nationalism," *Canadian Journal of Political and Social Theory* 10, no. 1–2 (1986): 199; see also Edward Jones-Imhotep, *The Unreliable Nation: Hostile Nature and Technological Failure in the Cold War* (Cambridge, MA: The MIT Press, 2017).

In addition to being major funders for scientific research and industrial R&D, governments are also key adopters of new technologies and shape their development through their specific needs and requirements. On the other hand, this history also points to the interplay between conceptions of good or "rational" government[317] and ideas about machine intelligence. Even before AI was defined as an object of inquiry let alone a field, it was systems like the state, markets, and governments that were recognized as the bearers of a new form of non-human rationality. By recasting intelligence in organizational terms, this formulation informed how humans and later machines were themselves reconceived of as both bearers of intelligence, generalizing this highly managerial and structural understanding of intelligence beyond the confines of the social systems around which it was originally articulated. Not only did this proximity anticipate the ongoing adoption of AI as a tool of government, but it also continues to animate how models like neural networks are used to not only validate new approaches to government and government organization, but also implement them. If neural networks and their conceptualization of intelligence as reducible to networks of 'dumb' units seem to provide a powerful analogy for the organization of contemporary governments, it might very well be because this model and others have been historically deployed to reduce the reliance of governments on trained labour and restore a certain degree to top-down oversight in large systems like themselves. Bridging both perspectives together, this chapter then proposes to approach neural networks' third and current iteration as intimately linked to postwar efforts to reshape the Government of Canada itself as a distributed albeit carefully managed network of 'simple,' untrained workers.

[317] Pierre Elliott Trudeau, "Federalism, Nationalism and Reason," in *Federalism and the French Canadians* (Toronto, Canada: Macmillan of Canada, 1968), 182–203; see also Albert Breton et al., "An Appeal for Realism in Politics," *Canadian Forum* 44 (1964): 29–33; Pierre Elliott Trudeau, "Functional Politics," in *Against the Current: Selected Writings 1939-1996*, ed. Gérard Pelletier (Toronto, Canada: McClelland & Stewart, 1996), 27–28.

3.2 From Nation- to Network-Building: A Media History of Canadian Federalism

Away from neural networks and servomechanisms, computers and black boxes, the Canadian state's experiments in network building, organizational reforms, and new political technologies began with a somewhat more prosaic project—that of broadcasting regulation. With Québec nationalism, Indigenous claims for sovereignty, and an increasingly diverse cultural fabric eroding Canada's self-image as a white, English-speaking, Protestant nation, federal administrators, members of parliament, and Canadian intellectuals alike all strived from the 1950s onward to identify how best to govern a highly decentralized nation with no clear identity. In the wake of the Royal Commission on Radio Broadcasting, whose 1929 report had identified mass media like radio as "a great force in fostering a national spirit [...] in a country of vast geographical dimensions",[318] many of these figures singled out media regulation as a privileged means to exercise a new form of government. More specifically, media regulation came to be seen as a powerful tool for the Canadian state to enforce its agenda both nationally and internationally. At the national level, media regulation became a central part of Canada's postwar security policy. By engineering national cohesion, media regulation provided "the bulwark of security" against internal threats in "the absence of security in either the military or the economic realm".[319] At the international level, it became recognized as a powerful tool to embed "a national and centrist cultural regimen into the fabric of Canadian citizenship"[320] and as such distinguish the latter from that of Canada's closest allies, be it the United Kingdom or the United States. Amidst settler-

[318] John Aird, *Report of the Royal Commission on Radio Broadcasting* (Ottawa, Canada: Queen's Printer, 1929), 6.
[319] Kevin Dowler, "The Cultural Industries Policy Apparatus," in *The Cultural Industries in Canada: Problems, Policies and Prospect*, ed. Michael Dorland (Toronto, Canada: James Lorimer & Company, 1996), 329.
[320] Mark Kristmanson, *Plateaus of Freedom: Nationality, Culture, and State Security in Canada, 1940-1960* (Toronto, Canada: University of Toronto Press, 2014), 87.

colonial anxieties about nationhood, land ownership, and self-determination[321], media regulation was thus recast into something which, while not an object of "official responsibility […] a generation ago"[322], could be used to ensure the proper exercise of government by both reaffirming Canada's sovereignty and ensuring its internal cohesion.

This perceived imperative to increase government involvement in the realm of media regulation contributed to the appointment of another royal commission in 1955: the Royal Commission on Broadcasting. Headed by paper industrialist Robert Fowler, the commission was convened with the mandate of exploring the use of television to not only promote national cohesion, but also altogether transform the practice of government. In its final reports, the commission notably laid out a vision of television as playing a role equivalent to the one once fulfilled by the railway. Claiming that Canada's unification into a single state would have been both unthinkable and unfeasible without the railway, Fowler added that the responsibility to hold the country together now encumbered to the medium of television. Gesturing at the work of Harold Innis, whose theory of communication posited that each medium "implies a bias in the cultural development of civilization"[323], Fowler claimed that postwar states could best maintain, and intervene on, themselves by purposefully regulating and deploying the latest communication technologies. Of these, Fowler singled out television, which he described as uniquely positioned to restore federal oversight both within, and at times beyond, the Canadian government's usual legislative powers. For these reasons, Fowler thus promoted broadcasting regulation "a legitimate

[321] see Bruno Cornellier, "The 'Indian Thing': On Representation and Reality in the Liberal Settler Colony," *Settler Colonial Studies* 3, no. 1 (2013): 49–64; Glen Coulthard, "Subjects of Empire: Indigenous Peoples and the 'Politics of Recognition' in Canada," *Contemporary Political Theory* 6 (2007): 437–460.
[322] Vincent Massey, *Royal Commission on National Development in the Arts, Letters and Sciences* (Ottawa, Canada: Edmond Cloutier, Printer to the King's Most Excellent Majesty, 1951), 5.
[323] Harold Innis, *Empire and Communications* (Oxford, UK: Oxford University Press, 1950), 216.

role of government in Canada"[324], to the point of advocating for making both media regulation and the creation of publicly owned channels prerogatives of the federal government. Described as an extension of the railway for its capacity to hold together the country's vast territory and diverse population, television was then framed by Fowler and the other commissioners as a privileged means to restore the federal government's capacity to exercise control over the circulation of information throughout the country and, by extension, govern the nation itself.

But more importantly, it is from this broader reconceptualization of television as both an object and a means of government that emerged the first comprehensive engagement with the notion of network in the federal literature. Throughout the commission's reports, Fowler not only used the word in its literal sense to refer to the various structures necessary to connect Canada's vast territory—rail networks, television networks, etc.—but also used the term in a more figurative sense to capture what he saw as the essence of the Canadian state. In his discussion of the now-defunct public station Dominion Network, for instance, Fowler went as far as promoting the latter's name as a powerful metaphor for Canada itself. As a nation whose existence was predicated on "state control and elements of public monopoly in relation to [….] media of communication"[325], Canada was conceived of by Fowler as itself a highly mediated entity indistinguishable from the communication networks constituting it. From there, Fowler specified that Canada should not only be conceived of as a distributed system held together by its networks, but should also be actively managed and governed as such to avoid its subjection and absorption by other, stronger networks. For beyond the internal threats faced by the Canada state, Fowler singled out as the main obstacle to its survival "the powerful attraction and influence of the United States"[326], which he claimed

[324] Robert Fowler, *Royal Commission on Broadcasting* (Ottawa, Canada: Queen's Printer and Controller of Stationery, 1957), 7–13.
[325] Fowler, 10.
[326] Fowler, 9.

could only be countered through increased government involvement in managing *all* networks. Beyond television and broadcasting, Fowler also listed the transcontinental railway, the national bank system, and the air transportation system as some of the many networks which the federal government should carefully manage to stop the “natural flow of trade, travel and ideas” from running “north and south” and instead make it “run east and west”[327].

But beyond questions of broadcasting regulation, this reconceptualization of Canada as not only dependent on networks, but also a network itself, echoed broader concerns with the structure and organization of the federal government. For in the wake of the Royal Commission on Broadcasting, Conservative Prime Minister John Diefenbaker (1957-1963) appointed yet another commission—the Royal Commission on Government Organization—with the specific aim of investigating “the ‘how’ rather than the ‘why’ of government”[328]. As the commissioners noted, the sheer size of the federal government had nearly quadrupled since the beginning of World War II, reaching a total of nearly 216,000 federal employees by 1960[329]. And while the personalized managerial style of the civil service had until then been conducive to tackling its ever-changing responsibilities, the utter disorganization of the federal government had become so obvious by the commission’s appointment that commentators, journalists, and political opponents alike all called for a profound reorganization of the federal bureaucratic machine. In response, the commission advocated for doing away with the federal government’s *ad hoc* approach to management. Reconceiving of the Canadian public service as itself a network-like system, it emphasized that top-down oversight could be restored over such a distributed and decentralized entity by standardizing tasks, streamlining key operations, and relocating all meaningful decision-making

[327] Fowler, 9.
[328] John Glassco, *Royal Commission on Government Organization, First Report on Progress* (Ottawa, Canada: Queen’s Printer, 1961), 2.
[329] Glassco, 35–38.

at the top. In its organizational formulation, the notion of network emerged as a model emphasizing structures, organization, and processes over people, judgment, and experience, to the point of reconceiving of organization as the main determinant of government. In continuity with Fowler's previous reconceptualization of Canada as an effect of its networks, the Royal Commission on Government Organization then operationalized this view by reframing the Government of Canada and the whole of federal politics as ultimately reducible to the structures, processes, and mechanisms underpinning them.

While the commission's reports were promptly tabled by the newly elected government of Liberal Prime Minister Lester B. Pearson (1963-1968), who remained committed to the informal, deliberative ethos of the Canadian civil service, their emphasis on organization, processes, and network-like structure nevertheless made its way into the federal bureaucratic machine in a technological form. For of all the recommendations formulated by the Royal Commission on Government Organization, the one that was adopted by the Pearson administration was that of integrating a new technology in particular—namely, the computer—within the Canadian civil service to "create new administrative 'machine shops'"[330]. While the purpose of these "shops" was first conceived of as tackling the data-processing needs of "administrators and operators throughout the organization"[331], it was instead the scarcity of certain forms of professional labour that motivated the creation of these computing centres. In 1966, Pearson announced his government's intention to make the publication of all federal documents in both French and English mandatory across all levels of the Canadian government. While only turned into law in 1969, this announcement initiated broader efforts throughout federal agencies to find ways to make

[330] John Glassco, *The Royal Commissionn on Government Organization, Volume 1: Management of the Public Service* (Ottawa, Canada: Queen's Printer, 1962), 45.
[331] Glassco, 45.

this policy's implementation possible. Given the scarcity of trained translators, and the unwillingness of federal institutions to invest in training more of them, federal agencies explored ways to reduce their reliance on human translators by automating part of the translation process. These efforts notably led to the Canadian government's first experiments in computing research, but also greater efforts to reorganize the whole of the civil service in a way that would accommodate the adoption of this technology at a large scale.

3.3 Networking at Work: Turning People into Nodes

Despite the widespread enthusiasm for new ideas about networks, systems, and communication throughout federal institutions, the Canadian government's involvement in computing research remained quite limited until the mid-1960s. Interwar investments in physics has indeed contributed to creating the demand for the first generation of professionally trained human computers[332], but no computer of the digital kind could yet be found on Canadian soil by the end of the war. While Canada's military and civil servant elites agreed that the country's lack of expertise in that field constituted a major obstacle to its long-term economic prosperity and national security, they also recognized the limited size of the Canadian economy as a major obstacle to the creation of a homegrown, local electronics industry. Divided between a postwar policy of cooperation and specialization, on the one hand, and the pursuit of technological sovereignty, on the other hand[333], federal institutions adopted a hybrid approach, which promoted computing as an integral part of the different research priorities set by the government.

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[332] Richard Jarrell and Yves Gingras, "Introduction: Building Canadian Science," in *Building Canadian Science: The Role of the National Research Council* (Ottawa, Canada: Canadian Science and Technology Historical Association, 1991), 1–17; Yves Gingras, *Les Origines de La Recherche Scientifique Au Canada: Le Cas Des Physiciens* (Montréal, Canada: Les éditions du Boréal, 1991).

[333] see John Vardalas, *The Computer Revolution in Canada: Building National Technological Competence* (Cambridge, MA: The MIT Press, 2001), 173–80.

Spearheaded by the National Research Council (NRC), this policy translated into targeted investments in communication technologies[334], nuclear physics[335], and medical research[336], on the condition that all these endeavours make use of the latest computing technologies to pursue their research goals. Without itself partaking in these research endeavours, the NRC provided the necessary funding for the acquisition of the first computers by Canadian universities, first at the University of Toronto (1948) and then at McGill University (1959), with the aim of building the country's computing capabilities. By the 1960s, the federal government had thus allowed for a small pool of programmers and computer scientists to emerge in the country's main cities but had undertaken no research of its own in that sphere.

It is only over the course of the 1963-1969 Royal Commission on Bilingualism and Biculturalism, which recommended that all federal documents be published in both English and French, that public administrators, civil servants, and politicians alike first considered the computerization of some of the federal government's operations. With 90% of all federal documents being redacted and circulated in English only at the time, few resources had been invested in both training and retaining professional translators, to the point that their overall scarcity threatened the implementation of the commission's recommendations. Anticipating this outcome, the general manager of the Canadian Government Printing Bureau, G. B. Watts, undertook to rally other agencies around the creation of a publicly funded, applied research program in the field of machine translation. As the federal government's primary research body, the NRC was for Watts an obvious contender to spearhead this work, but its president Bristow

[334] Vardalas, 45–78.
[335] Luc Chartrand, Raymond Duchesne, and Yves Gingras, *Histoire Des Sciences Au Québec de La Nouvelle-France à Nos Jours* (Montréal, Canada: Les éditions du Boréal, 2008), 407–62.
[336] Alison Li, "Expansion and Consolidation: The Associate Committee and the Division of Medical Research of the NRC, 1938-1959," in *Building Canadian Science: The Role of the National Research Council* (Ottawa, Canada: Canadian Science and Technology Historical Association, 1991), 89–104.

Ballard initially remained unconvinced that the translation of public documents required a technological solution. Following several feasibility studies, however, which ultimately concluded that "develop[ing] a system of machine-aided translation" would be more economical than "increas[ing] the supply of human translators by inducements of salary and working conditions"[337], Ballard and the NRC turned to the Treasury Board to support the development of computer-based, translation tools designed to increase the output of the government's in-house translators. While mostly autonomous in the use of its allocated budget, the NRC had no established program to support computing research and requested an exceptional financial commitment from the Treasury to investigate the use of "modern electronic data processing equipment to facilitate the translation of government documents from English to French"[338]. Less than a month later, the Treasury approved the NRC's request and provided it with a grant of "$1,6 million over the period 1965-1971" to support "a full-scale research project in machine translation"[339], which effectively instigated the federal government's first attempt to enhance its operations through computing means.

By that time, the NRC had indeed provided itself with a Computation Centre, but the latter's sole purpose consisted in selling computer time to other agencies. Following the Treasury Board's grant, however, the NRC's machine translation program became the defining endeavour of its Computation Centre—if not of the agency as a whole—insofar as it became recognize as a rich use case for the implementation of computing technologies in government settings[340]. Not

[337] Bryce Kendrick, *Report on the Conference on Computational Linguistics, New York City, May 1965* (Ottawa, Canada: National Research Council, 1965), 1.
[338] F. T. Rosser, *Letter to Dr. G. F. Davidson Titled "Machine Language Translation," from July 27, 1965* (Ottawa, Canada: National Research Council, 1965), 1.
[339] Cabinet of Canada, *Letter to Dr. B. G. Ballard from the National Research Council, from August 20, 1965* (Ottawa, Canada: National Research Council, 1965), 1.
[340] see S. D. Baxter, *Letter to Dr. D. W. R. McKinley, Director of the Radio and Engineering Division, from August 1, 1968* (Ottawa, Canada: National Research Council, 1968).

only did the program provide a first instance where the computer came to be seen as something more than a tool for crushing numbers, but it also for the first time raised the prospect of using computers to reshape the organization of work and labour within the government. For in comparison to the NRC's German and American counterparts, which aimed to fully automate the translation process, the program adopted the "much more modest objective whereby the machine is simply used as one of a number of tools available to the translator"[341]. Instead of trying to altogether replace human translators, the program aimed to capitalize on "the dual trends toward ever-cheaper computing and ever-more expensive human labour" by creating "networks" of human workers and computing machines that could produce translations in an assembly-line manner[342]. When officially launched at the end of 1965, the program's main goal then consisted in developing a system that could standardize the translation process and break it down into simpler steps, to the point where the output of professional translators working individually could be matched by untrained albeit computer-aided translators working as a group. Away from its previous, more metaphorical use in the federal literature, the notion of network was thus recast in the context of this program as a new, technologically enhanced organizational model, where complex tasks previously fulfilled by trained professionals could be broken down and distributed across networks of computer-aided workers.

While initially slowed down by the challenge of finding researchers with the necessary expertise in both computing and linguistics to pursue this work, the NRC's machine translation program ultimately funded application-based programs at the University of Saskatchewan, the Université de Montréal, and the Cambridge Language Research Unit. At Cambridge, the team

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[341] National Research Council, "Machine Language Translation and the National Research Council: History of M.L.T. at N.R.C. and Our Currently Sponsored Projects" (Ottawa, Canada: National Research Council, 1966), 5.
[342] E. G. Manning, *Letter to Dr. B. A. Gingras of the National Research Council, from February 8, 1971* (Ottawa, Canada: National Research Council, 1971), 1.

adopted a strategy that consisted in mapping recurrent "units of discourse" in the federal literature, establishing French equivalents for each of them, and developing a computer program capable to recognize and substitute them[343]. At the Université de Montréal, the researchers promoted a more formalist approach, which aimed to apply to linguistics "techniques of precise description which are derived from mathematics"[344]. At the University of Saskatchewan, finally, the team resorted to a statistically inclined approach, which combined the use of parsing methods with the development of a computer searchable dictionary[345]. While distinct, these three approaches all aimed to develop highly interactive systems which, when properly operated, could produce usable translations at a lower cost than with professional translators. As the three teams began to put together their first prototypes, however, the prospect of building a robust translator became increasingly unlikely. In response, the teams all shifted their focus away from the conceptual soundness or cognitive plausibility of their approaches and instead began to compete with one another on the basis of how unskilled their systems' intended users could be. By the time the NRC required that the teams present their prototypes to federal administrators, the level of training—or lack thereof—required to use the different systems had become the main metrics to evaluate the success of the various systems, to the delight of the budget-minded government officials who attended the showcase.

Due to the lack of progress of the Cambridge team, only the Montréal and Saskatchewan programs were still under contract when the first prototypes were presented at a joint event held at Université de Montréal in 1971. On the Montréal side, the system produced, Système-Q, could

[343] National Research Council, "Machine Language Translation and the National Research Council: History of M.L.T. at N.R.C. and Our Currently Sponsored Projects," 3.
[344] Université de Montréal, *Machine Translation Project at Université de Montréal: Brief Interim Report - January 1969* (Ottawa, Canada: National Research Council, 1969), 1.
[345] see Charles Stock, *Mechanical Translation Research Report - University of Saskatchewan: Programming* (Ottawa, Canada: National Research Council, 1970), 1.

translate basic sentences into a French that was “understandable, but not very good in style”[346]. Système-Q, however, was still considered by the attendees as a promising alternative to unaided translation, as it was deemed “easier to engage French editors who can polish a rough translation than to find or train skilled bilingual translators”[347]. On the Saskatchewan side, the system presented relied on a more hybrid approach, by outputting literal translations of a text’s verbs and nouns, while listing all potential pronouns and articles that might link them. Producing translations such as “L’Amérique du Nord comprend six régions principales naturelles (*qui/que/ce qui/ce que*) sont (*à la fois/aussi bien que*) physiograpiques et géologiques"[348], the system could be operated by “stenographers, […] students, […] or girls,” as one administrator emphasized, whose job would be to select the right pronouns and articles to render the text legible[349]. Enthralled by the prospect of using these systems to outsource federal agencies’ translation needs to “an inexperience translator or even a person with no training in translation”[350], the officials who attended the event marvelled at how these systems could “immediately relieve the pressures imposed on [their] limited resources”[351]. With the program itself coming to an end in 1971, it is then a highly specific vision of both organization and computing which emerged from it: one where greater efficiency and reduced costs could be achieved by using computers to turn complex processes into discrete tasks, which could be performed by low-wage workers whose organization into networks ultimately evoked more of an assembly line than anything else.

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346 Université de Montréal, *Machine Translation Project at Université de Montréal: Brief Interim Report - January 1969*, 2.
347 Université de Montréal, 2.
348 D. A. Sinclair, *Letter to Dr. Tupper of the National Research Council, from February 27, 1970* (Ottawa, Canada: National Research Council, 1970), 2.
349 Sinclair, 1.
350 André Gouin, *Machine Translation in Canada* (Ottawa, Canada: National Research Council, 1972), 16.
351 Gouin, 12.

Anticipating neural networks' reliance on, and devaluation of, various forms of human labour, the federal government's first experiments in computing research then provided the blueprint for a certain way of organizing workers and machines alike. While the two-year program extension awarded by the Treasury to implement both systems in government settings failed to produce any meaningful results, it nevertheless crystallized a broader attempt to reduce the government's reliance on skilled labour, situated knowledge, and human judgment. Given the right tools and structures, it was assumed that skilled labour could be standardized, broken down, and atomized to the point of being fulfilled by workers who were not only a much lower pay scale, but who could also be more easily replaced or repurposed. For instance, while the Montréal system aimed to do away with bilingualism as a needed competency for translation, the Saskatchewan program for its part raised the prospect of turning the white-collar position of translators into a highly gendered, low-wage position fulfilled by stenographers and secretaries on top of their other responsibilities[352]. Under the pretense of optimizing government processes, these experiments promoted a broader vision of computing as a technology uniquely positioned to reduce the government's reliance on skilled labour, restore top-down oversight, and altogether eliminate opportunities for creativity throughout the bottom half of the government's workforce. From the very beginning of the Government of Canada's experiments in computing technologies, it was thus mid-ranking, government clerks who were singled out as the privileged targets of technocratic attempts to reorganize government operations, both for the type of operationally relevant tasks they performed and the perceived threat they represented to top-down oversight.

[352] Friedrich Kittler's discussion of women's arrival into the workforce as stenographers in the early 20th century provides a key historical precedent to such attempts at rationalisation. To the same extent that training women to become stenographers involved them learning to dictate "on typewriters […] without comprehending what was being dictated," this attempt at turning translation into a form of low-wage, gendered labour was similarly predicated on emptying out the translation process from any form of interpretation or meaning-making. See Friedrich Kittler, *Gramophone, Film, Typewriter* (Stanford, CA: Stanford University Press, 1999), xxv; see also Siegfried Kracauer, *The Salaried Masses: Duty and Distraction in Weimar Germany* (London, UK: Verso, 1998), 28–46.

While officially terminated in 1973, with little to show for itself except for a mountain of reports and two mostly unusable prototypes, the NRC's machine translation program nevertheless provided one of the main case studies for the Government of Canada's first policy paper on computing and its applications. As the outcome of a four-year study on the use of computing technologies in federal agencies, that paper posited that networks of computer-aided workers constituted the best organizational model to not only perform complex government operations, but also relocate the intelligence required from their completion from the workers themselves to the structures they occupied. Throughout the paper, the administration of then-Prime Minister Pierre Elliott Trudeau (1968–1979, 1980–1984) notably stated that the computer's "potentially revolutionary benefits" could only be secured through its use as a managerial technology[353]. Through a mix of "future-oriented analyses of needs, technological developments and policy"[354], the paper claimed, computers could be turned into a privileged means to restore "control over [the federal government's] key activities and services"[355] by turning its many agencies and departments into tightly interconnected "computer/communications information networks" [356]. Faced with an ever-growing civil service whose disorganization constituted the main challenge to the implementation of federal policies according to the paper, the government was forced to turn to such technologies to not so much empower or connect workers as exercise "orderly, rational and efficient" management over them [357]. Part communication, part control technology, computing was thus deemed an area of "natural government responsibilities"[358] insofar as it could be used to reshape the federal bureaucratic machine from a hierarchical albeit *ad hoc* entity to a highly

[353] Gérard Pelletier, *Computer/Communications Policy: A Position Statement by the Government of Canada* (Ottawa, Canada: Information Canada, 1973), 1.
[354] Pelletier, 7.
[355] Pelletier, 17.
[356] Pelletier, 1.
[357] Pelletier, 2.
[358] Pelletier, 4.

distributed, network-like structure over which control could be exercised through increased interdependency and reduced opportunities for discretion. If the computer constituted "the central nervous system of future society"[359], as the paper stated, it was thus insofar as it assumed that such a system was ultimately overseen by a central, brain-like entity like the highest levels of government in that specific case.

The subsequent programs instigated by the federal government readily captured how this model of "orderly, rational and efficient" management translated into a vision of networks as structures that could be made to embody specific government goals not so much despite, as thanks to, their distributed nature. Throughout the 1970s, the Trudeau administration approved several other applied computing programs, which all aimed to solidify the managerial principles championed by the NRC's machine translation project in the form of physical infrastructures that could expand these principles beyond the confines of government. CANUNET (1972-1973), for instance, which was initially conceived of an Internet-like infrastructure designed on the model of ARPANET, was deployed with the aim of restoring federal oversight over a fiercely protected area of provincial jurisdiction—namely, university-level research. As explained in one report, CANUNET was first introduced as a means to not only facilitate the exchange of data across Canadian universities, but also allow federal funding bodies to keep track of the projects they sponsored[360]. By creating a permanent network of computerized communication across universities, however, the long-term goal was to allow the free exchange of knowledge and information among them and ultimately encourage Canadian universities to both collaborate together and specialize in increasingly specific subfields[361]. By cultivating greater interdependency

[359] Pelletier, 4.
[360] CANUNET Advisory Committee, *A Proposal for a Canadian University Computer Network (CANUNET)* (Ottawa, Canada: Department of Communications, 1972), 2.
[361] CANUNET Advisory Committee, 6.

among Canadian universities, the goal was to reduce provincial governments' capacity to impose their research priorities over them and turn federal funding bodies into the *de facto* mediators of Canadian universities' overall research agenda. Seen as the starting point for the creation of a broader Canada-wide network connecting public and private institutions alike[362], CANUNET then embodied a vision of networks as politically potent structures, whose distributed, multilateral, and collaborative nature was seen as enabling greater centralized oversight.

While CANUNET failed to materialize beyond the prototyping stage, it nevertheless led to a second program, which aimed to extend such networked functionalities to the confines of the home. Known as Telidon (1978-1985), the program aimed to develop a videotext service that would turn home televisions into connected, interactive, and information-driven devices. By using telephone lines to connect televisions to centralized computers, Telidon was designed to give Canadian viewers access to "large computer-based information sources"[363] of publicly funded content and government data. Developed at a time when computers were still restricted to corporate and institutional settings, Telidon offered a first, personalized computing experience, while also being conceived of as an infrastructure that could be used by the federal government to both monitor and shape its citizens' activities. In an internal report published in the late 1970s, federal administrators described Telidon as an opportunity to exercise greater social control outside of traditional institutions by subjecting Canadians to more "flexible rules and regulations"[364]. Describing how this technology could one day enable Canadians to work from home, but also subject them to various forms of automated management, the report framed Telidon

[362] CANUNET Advisory Committee, 33.
[363] H. G. Bown et al., *A General Description of Telidon - A Canadian Proposal for Videotex Systems* (Ottawa, Canada: Communications Research Centre, 1978), 1.
[364] John Madden, *Videotex in Canada* (Ottawa, Canada: Department of Communications, 1979), 17.

as a privileged tool to bring the home "under computer control"[365]. At the same time as Telidon raised the prospect of offering greater interactivity and connectivity, it also embodied a more flexible model of control through which the latter could be exercised not so much through direct interventions and deliberate planning but instead by making human activities of all kinds dependent on computerized networks. Seen as a technological extension of the government itself, Telidon thus represented a privileged tool to turn Canadian homes into nodes of a larger network over which government could be exercised technologically.

What unites these different programs, from the NRC's machine translation project to CANUNET and Telidon, is a conception of networks as not only a privileged model to organize and manage labour, but also a powerful metaphor for the governance of a country as large and decentralized as Canada. Be it by turning white-collar professionals into replaceable workers, independent universities into interconnected hubs, and private citizens into networked ones, these programs all aimed to embed into the fabric of Canadian citizenship not only a certain ideal of connection, but also of interdependence. The type of "rational" management that such a model promoted implied that autonomy—be it manifested by the judgment of trained professionals, the self-imposed research priorities of politically independent universities, or the private space of the home—constituted an obstacle to purposeful, conscious planning and thus required various technological interventions in order to be minimized. In an especially telling passage from a Telidon report, for instance, a federal administrator described that technology as representing yet another instance of "[m]achine intelligence […] further eroding our independence"[366]. But far from decrying that phenomenon, he instead described this erosion as unavoidable in an increasingly complex world. For as he wrote, meaning and order could no longer be produced at the level of

[365] Madden, 16.
[366] Madden, 16.

individuals and it was then up to systems like government to produce social order and meaning by deploying the necessary tools and processes to concentrate information at the top[367]. The understanding of rational, purposeful management which emerged from such conclusions was then one as a phenomenon that was not only networked in nature, but also applied more readily to structures, machines, and organizations than to people.

Far from anecdotal, this broader reconceptualization of rationality and purpose as by definition networked in nature coincided with the beginning of AI research in Canada. While initially defined around hard-coded heuristics and operations upon symbols[368], AI had by then collapsed under the weight of its promoters' unfulfilled promises. With major funding bodies gradually decreasing their support, the field of AI underwent throughout the 1970s its so-called first winter, a period of stark underfunding and institutional abandonment that contrasted with the vast resources the field previously enjoyed[369]. And yet, this "winter" also allowed for scholars previously excluded from the field to bring forward alternative understandings of machine intelligence all the while competing on more equal footing with their once heavily funded peers. While initially defined in opposition to neural networks and cybernetics more broadly, AI had become at that point more accommodating as a field in terms of the approaches, techniques, as well as sites it encompassed. For away from AI's early hubs like the MIT and Stanford University, it is at the newly created Canadian Institute for Advanced Research that neural networks were first recast into an operational approach to machine intelligence, thanks partly to that institution's adoption of networks as a privileged organizational model to carry that type of work.

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[367] Madden, 16–17.
[368] John McCarthy et al., "A Proposal for the Dartmouth Summer Research Project on Artificial Intelligence," 1955.
[369] see Cardon, Cointet, and Mazières, "Neurons Spike Back: The Invention of Inductive Machines and the Artificial Intelligence Controversy."

3.4 Networked Intelligence: From Research Networks to Neural Networks

Be it in governmental reports[370], the technical literature[371], or even the popular press[372], the Canadian Institute for Advanced Research (CIFAR) is regularly characterized by its contribution to the field of AI in Canada. More often than not, it is described as having almost single-handedly catalyzed the rise of the machine learning model known as "neural networks"—a biologically inspired, statistical approach to pattern extraction—at a time when the field of AI itself was struggling to survive. But CIFAR's lesser-known, and arguably most palpable, contribution instead consisted in having promoted another type of network—namely, research networks—as a privileged model for the organization of research.

While initially conceived of in 1978 as the Canadian equivalent of the prestigious Institute for Advanced Study, CIFAR—or, at the time, CIAR—failed to secure the necessary endowment to reproduce the latter's model. After years of fruitless fundraising, carried out with the promise of building capacity in fields with great technoscientific and industrial import, the initiators of CIFAR developed a hybrid model, which consisted in financially supporting researchers based at publicly funded universities to pursue research with great attractiveness to both philanthropic and private donors. After having surveyed the research interests and priorities of key donors, the CIFAR scientific committee shortlisted three research areas—astrophysics, population health, and artificial intelligence (AI)—as the most promising themes for the institute's first research program. After almost a year of deliberation, which led to astrophysics being ruled out as already too mature a field for CIFAR to make an impact and population health as too broad, AI was selected as the theme of CIFAR's inaugural program in 1982. Using a cross-affiliation model, it appointed rising

[370] e.g., Departmental Evaluation Committee, "Evaluation of the Canadian Institute for Advanced Research" (Ottawa, Canada, 2013).
[371] e.g., Goodfellow, Bengio, and Courville, *Deep Learning*.
[372] "How Canada's Unique Research Culture Has Aided Artificial Intelligence," *The Economist*, 2017.

figures in the field as fellows, who remained based at their respective institutions while being required to collaborate closely with one another. Starting with a cohort of eight fellows—four at the University of British Columbia (UCB), two at University of Toronto (UofT), and two at McGill University—CIFAR's AI program set the stage for a decentralized, network-like approach to research management, with CIFAR at its centre.

While now widespread both in Canada and abroad, this model represented at the time an innovation from a research perspective, but also a research management one. In the words of CIFAR's founding president Fraser Mustard, this network-like approach was seen as especially well adapted to overcome the obstacles inhibiting "the full use of the country's intellectual resources"[373]. Of these, Fraser identified Canadian institutions' limited resources, but also the sheer size of the country, which he framed as the main obstacle to the free circulation of ideas. In both cases, however, the solution proposed by CIFAR was to create new bridges, links, and connections across localities, fields, and industries to circumvent both economic limitations and physical distance alike. So new was this model, and so widely recognized were these barriers by Canada's political class, that in 1982, when the Royal Commission on the Economic Union and Development Prospects for Canada was appointed, CIFAR provided one of the main case studies evaluated by the commissioners. Convened during Pierre Elliott Trudeau's last mandate, the commission was instructed to identify new strategies to ensure Canada's long-term economic prosperity in the face of both social and technological change. Beyond its promotion of free trade, for which it is now famous, the commission advocated for the federal government's renewed involvement in fostering both technological innovation and socio-economic equality. More specifically, it predicated the government's very capacity to respond "to ever more encompassing

[373] Fraser Mustard quoted in Craig Brown, *A Generation of Excellence: A History of the Canadian Institute for Advanced Research* (Toronto, Canada: University of Toronto Press, 2007), 68.

notions of equality" on the development of "new instruments and administrative technologies" capable to produce the necessary wealth to fund new welfare programs[374].

Of all the technologies it surveyed, the commission identified the computer as one uniquely suited to achieve such socio-economic aims. Singling out AI as one of its most promising applications, it promoted computers' capacity to "substitute […] human mental efforts"[375] as an opportunity to free Canadians from repetitive and intellectually straining jobs in corporate offices and public institutions. To identify how best to catalyze the development of this technology, the commission summoned CIFAR's Fraser Mustard to act as one of its key experts. Emphasizing how "nations with strength in one sector of a rapidly developing field have entrée to all sectors"[376], Mustard recast AI as a national imperative that should be pursued in order to ensure future prosperity. To do so, he recommended that the Government of Canada not only increases "the overall fund of knowledge and techniques open to their industries and institutions"[377], but also awards it on a similar model as that used by CIFAR. It is in fact precisely that model which appealed to the commissioners, among whom sat no other than its own architect. The commission's vice-chair, Clarence Barber, had been specifically selected for his contribution to founding CIFAR and has often been credited for having developed the network-like model that still characterizes the institute[378]. Described in their final report as a "private sector initiative undertaken with public sector support," this model represented for the commissioners a promising approach to "help Canada move to the forefront of technological innovation"[379] despite its limited

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[374] Donald Macdonald, *Report of the Royal Commission on the Economic Union and Development Prospects for Canada: Volume 1* (Ottawa, Canada: Privy Council Office, 1985), 26–27.
[375] Macdonald, 117.
[376] Mustard quoted in Macdonald, 117.
[377] Macdonald, 117.
[378] see Brown, *A Generation of Excellence: A History of the Canadian Institute for Advanced Research*.
[379] Donald Macdonald, *Report of the Royal Commission on the Economic Union and Development Prospects for Canada: Volume 2* (Ottawa, Canada: Privy Council Office, 1985), 205.

resources. Drawing from CIFAR's model, the commission recommended the establishment of "several technology-development centres [...] in computer technology and related fields"[380] to not only develop a coast-to-coast pool of expertise, but also create closer links across provinces, in a way that would transcend their individual interests and priorities. In continuity with the New Public Management movement and other businesslike models of governance in vogue at the time, it was then a highly distributed approach that the commission advanced—one which predicated the achievement of key economic and political goals at a national level on cultivating greater interdependence between universities, companies, and provincial governments across the country.

Apart from the pursuit of a free trade agreement with the United States, which became the commission's defining recommendation, the creation of the Networks of Centres of Excellence (NCE) program was arguably the second most important policy that came out of it. Created under the administration of Prime Minister Brian Mulroney (1984-1993) with an approved envelope of $240 million, the program aimed to create networks of partnerships across provinces around research topics that were deemed strategic to Canada's long-term economic prosperity. While distinct from the NCEs, CIFAR provided a clear—and acknowledged—inspiration for that program[381] and became from its creation onward a regular beneficiary of federal grants. It is thanks to that new, steady source of funding, which freed the CIFAR leadership from the constant struggle of securing financial support, that CIFAR expanded its mandate by not only setting upon new research programs, but also bringing in new contributors—as well as new perspectives—into its AI program. This latter transition was spearheaded by cognitive scientist Zenon Pylyshyn, himself a leading figure in the field, who had just been appointed director of AI research. Contrarily to his predecessor William Tatton, who had selected fellows based on their shared research interests,

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[380] Macdonald, 145.
[381] see Industry Science and Technology Canada, "Networks of Centres of Excellence" (Ottawa, Canada, 1989).

Pylyshyn focused on bringing in representatives from all the main schools of thought and approaches to AI research. As he himself noted, Pylyshyn was committed to fostering "interaction across disciplinary, institutional and regional boundaries"[382] in a way that would deviate from AI's previous articulation around a single strand of symbolically inclined research. Throughout his tenure, Pylyshyn pursued this goal by not only appointing new fellows such as control theorists Peters Caines and George Zames and symbolists like John Mylopoulos and Hector Levesque, but also securing appointments at Canadian universities for scholars working on new approaches to AI. These included Wolfgang Bibel, a German logician who joined the UBC faculty, and the American roboticist John Hollerbach, who was provided with an appointment at McGill. The resulting network, which spanned across both sites and approaches, then built on the assumption that disagreements, controversies, and opposing agendas could be ultimately resolved if their representatives were made to inhabit, and compete within, the same network.

Pylyshyn's commitment to turning CIFAR's AI program into a space where distinct approaches could be to inhabit the same network was most notably illustrated by the recruitment of one of his own intellectual antagonists Geoffrey Hinton, then at Carnegie Mellon. For while Pylyshyn posited that the type of computing relevant to the study of both human and machine cognition necessarily involved manipulating symbols[383], Hinton for his part advanced that all the processes underpinning cognition were reducible to both the material organization of the brain and the mathematical principles it embodied. Introduced to the study of neural nets while completing his PhD in the then newly created Department of Machine Intelligence and Perception at

[382] Zenon Pylyshyn quoted in Brown, *A Generation of Excellence: A History of the Canadian Institute for Advanced Research*, 63–64.
[383] Zenon Pylyshyn, "Cognition and Computation: Issues in the Foundations of Cognitive Science," *Behavioral and Brain Sciences* 3, no. 1 (1980): 154–69; Zenon Pylyshyn, *Computation and Cognition: Toward a Foundation for Cognitive Science* (Cambridge, MA: The MIT Press, 1984).

University of Edinburgh, Hinton worked against the rule-bound paradigm which first animated AI research. Promoting an understanding of representation as best understood in terms of "relational networks" in which "nodes and relations of various types [...] constitute a kind of grammatical knowledge"[384], Hinton found a more receptive audience among structurally inclined psychologists who recognized that "the currency of [cognition] is not symbols but excitation and inhibition"[385] than adherents of symbolic AI. Moving to the United States in the early 1980s to work with psychologist David Rumelhart, Hinton developed a research agenda in which the study of human information processing went hand in hand with the modelling of how parallelized, neural-like structures compute information. At its core, Hinton's work aimed to explain how incredibly complex and computationally expensive tasks like visual perception, speech, and spatial orientation could be executed by physically finite systems like brains and computers. Focusing primarily on neural networks, Hinton worked on developing highly parallelized computing architectures inspired by the structure of the brain[386].

Hinton's appointment as a CIFAR fellow in 1986 even coincided with the publication of Pylyshyn's now well-known critique of structuralist approaches to machine intelligence. Titled "Connectionism and Cognitive Architecture," the piece rejected Hinton's neural networks as only attractive to those who approach cognition from the perspective of its computational implementation and thus assume that cognition can "only be understood if we study it as neuroscience"[387]. Despite their disagreements, Pylyshyn was the main proponent for the

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[384] Geoffrey Hinton, "Relaxation and Its Role in Vision" (University of Edinburgh, 1977), 47.
[385] David Rumelhart and James McClelland, *Parallel Distributed Processing: Explorations in the Microstructure of Cognition* (Cambridge, MA: The MIT Press, 1987), 132.
[386] James McClelland, David Rumelhart, and Geoffrey Hinton, "The Appeal of Parallel Distributed Processing," in *Parallel Distributed Processing, Volume 1*, ed. David Rumelhart and James McClelland (Cambridge, MA: The MIT Press, 1986), 3–44; Scott Fahlman and Geoffrey Hinton, "Connectionist Architectures for Artificial Intelligence," *IEEE Computer* 20, no. 1 (1987): 100–109.
[387] Jerry Fodor and Zenon Pylyshyn, "Connectionism and Cognitive Architecture: A Critical Analysis," *Cognition* 28, no. 1–2 (1988): 82.

recruitment of Hinton, whom he considered as not only a leading figure of the connectionist movement, but also a potential agent for transformation for CIFAR itself. For by reducing the problem of intelligence to the question of how best to organize networks of "neuron-like computing elements"[388] so it is "the entire, distributed pattern of interacting influences among the units in the network that is doing the work"[389] (see Figure 4), Hinton defined the objective of AI as not so unlike that of CIFAR itself. In both cases, the challenge consisted in finding how best to organize limited resources and capabilities as "to get the most possible out of a simple network of connected units"[390]. Hinton's appointment at CIFAR even coincided with his articulation of a first procedure designed to fulfill such a goal, i.e., that of optimizing the connections among units so the task at hand becomes "encoded by a pattern of activity in many units rather than by a single active unit"[391]. Known as "backpropagation," this procedure consisted in "repeatedly adjust[ing] the weights of the connections in the network" as to minimize the difference between a net's actual and desired output for a given input[392]. While dismissed by many of his CIFAR peers as bearing little resemblance to how the brain functions[393], this method nevertheless provided a highly functional approach to embed complex operations into simple networks.

If this procedure's first use case—namely, "learning the associations of 20 pairs of random binary vectors of length 10"[394]—bore little practical application, it still provided an example of a complex task being performed at the level of the network itself, without being reducible to any of

[388] Hinton, McClelland, and Rumelhart, "Distributed Representations," 77.
[389] Hinton, McClelland, and Rumelhart, 85.
[390] Hinton, McClelland, and Rumelhart, 87.
[391] Hinton, McClelland, and Rumelhart, 88.
[392] David Rumelhart, Geoffrey Hinton, and Ronald Williams, "Learning Representations by Back-Propagating Errors," *Nature* 323 (1986): 533.
[393] e.g., Hector Levesque, "Making Believers out of Computers," in *Readings in Artificial Intelligence and Databases*, ed. John Mylopolous and Michael Brodie (San Mateo, CA: Morgan Kaufmann Publishers, 1989), 69–82.
[394] David Plaut, Steven Nowlan, and Geoffrey Hinton, "Experiments on Learning by Back Propagation," in *Technical Report CMU-CS-86- 126* (Pittsburgh, PA: Carnegie-Mellon University, 1986), 20.

its individual components. For beyond such limited use cases, it is the very prospect of restoring a certain degree of centralized control within similarly distributed systems that appealed to CIFAR's public sponsors. In a landmark report published the following year, the Government of Canada singled out AI as a technology uniquely positioned to improve government operations by providing "substitutes for [human] expertise"[395]. By raising the prospect of decreasing the government's reliance on skilled labour, AI was framed as a promising way to encode the knowledge and intelligence necessary for the completion of government operations within the tools used by government workers, who would no longer need to hold the necessary expertise to bear judgment on, or influence, the operations they fulfilled. In the image of neural networks themselves, it is then a view of government operations as independent from any of its individual components which emerged, with both the deskilling and reorganization of government workers being recast as privileged means to steer a large system like government towards desired ends.

The type of work pursued by Hinton in the following years with the support of both provincial and federal bodies directly mirrored this broader ambition of not so much replacing human workers as breaking down their tasks into smaller, more standardized ones. With grants from the Information Technology Research Center to research speech recognition, Hinton developed a time-delay neural network architecture designed to identify phonemes in sound samples of different lengths[396], whose intended use was to create phonetic transcriptions that could be then polished by human workers. With another grant from the same body, Hinton trained a neural network to recognize hand-written numbers on envelopes[397], with the stated aim of

[395] Peter McKinnon, *An Overview of AI & Recent Related Government Activities* (Ottawa, Canada: Ministry of State for Science and Technology of Canada, 1987), 4.
[396] Kevin Lang, Alex Waibel, and Geoffrey Hinton, "A Time-Delay Neural Network Architecture for Isolated Word Recognition," *Neural Networks* 3 (1990): 42.
[397] Geoffrey Hinton, Christopher Williams, and Michael Revow, "Combining Two Methods of Recognizing Hand-Printed Digits," *Artificial Neural Networks* 2 (1992): 54–56.

automating parts of the process involved in classifying and distributing mail. For the Canadian Institute for Robotics and Intelligent Systems, finally, Hinton developed a neural network that could interpret sonar readings to orient an imaginary robot—or person—in space[398], to be used for orienting workers and visitors alike with government buildings. While none of these applications were overtly political, they nevertheless raised the prospect of doing away with various forms of contextual or local knowledge. If successfully implemented in government settings, these applications would have all provided new ways to streamline operations, centralize decision-making, discipline workers, and remove opportunities for discretion—all things pointing to the more implicit objective of thinning the lower ranks of government bureaucracies. If neural networks provided both the tools and the metaphor to reconceive of large and disperse workforce as themselves networks of simple units, it is then because their development was part of a broader attempt to de-skill and de-professionalize workers, in order to make it easier to train, manage, and replace them.

Back at CIFAR, it is this very capacity of Hinton and of his highly operational approach to build connections with public funders that led to a similar streamlining of its AI program. As Pylyshyn then noted, the institute's efforts to "facilitate the transfer of knowledge and the development of a strong applied research sector"[399] had proven mostly unsuccessful by the turn of the 1990s, with Hinton's work constituting a much welcome exception to this perceived shortcoming. In the subsequent years, the capacity of fellows to secure links and partnerships with both private and public bodies gradually became the main source of validation for their work, which greatly advantaged those pursuing more applied research. While many of CIFAR's first

[398] Sageev Oore, Geoffrey Hinton, and Gregory Dudek, "A Mobile Robot That Learns Its Place," *Neural Computation* 9 (1997): 684–90.
[399] Pylyshyn quoted in Brown, *A Generation of Excellence: A History of the Canadian Institute for Advanced Research*, 64.

fellows saw their affiliation revoked by the mid-1990s, new fellows were, for their part, increasingly selected among those working on neural networks and their application in subfields like computer vision and speech recognition. Despite the multidisciplinary ambitions of CIFAR's network-like model, it is precisely this emphasis on building connections as an end in itself that ultimately led to a growing homogenization around the nodes that proved the most successful at it. In the image of neural networks, CIFAR's network approach did not then so much provide a model for the creation of new links as one for how interconnectedness and interdependence can create cohesion out of difference. At the same time as it promoted collaboration and transdisciplinary, CIFAR thus also provided a rich example of how clear research goals can be embedded into the very organization of research networks.

By providing both a highly operational approach to machine intelligence as well as embodying the idealized structure in which to carry that type of work, neural networks' third iteration then emerged as a solution to the problem of how best to organize distributed networks so control and cohesion can be restored. In this specific articulation, and before they would be relayed to a purely computational framework, neural networks promoted the idea that a certain degree of centralized control could be restored in distributed systems by simplifying the contribution of its individual components, promoting connections as an end in itself, and relocating the system's functions at the level of the network. That the human workers involved in formatting the 768 sound samples used for Hinton's speech recognition model or the 60,000 images used for his later work on computer vision received but a passing remark[400] might come as no surprise; and yet, it is symptomatic of the broader devaluation of local, contextual, and situated knowledge fuelled by this model's reconceptualization of all its components as "simple units." For Hinton to

[400] see Lang, Waibel, and Hinton, "A Time-Delay Neural Network Architecture for Isolated Word Recognition," 25–26; Alex Krizhevsky, "Learning Multiple Layers of Features from Tiny Images" (Toronto, Canada, 2009), 32.

recast AI's aim as that of identifying how best to organize "internal units [... so they] come to represent important features of a task"[401], it was then necessary for all the actors, resources, and organizations involved in neural networks' re-articulation, development, and implementation to be recast in similar structural terms. More than a biologically inspired model of machine intelligence, neural networks thus emerged in its current form as a structurally inclined approach to organization, in which control was exercised by not only rendering complex social contexts into nodes, networks, and simple units, but also acting upon them accordingly.

3.5 "Looking into the Mind of a Neural Network": Making Intelligence Operational

The implications of the previous section are manifold. In contrast with previous engagements with the governmental history of AI, which mostly focused on the role of government institutions in funding certain strands of research over others[402], I suggest a more intimate connection between conceptions of rational government and ideas about machine intelligence. In continuity with Matteo Pasquinelli[403], Johannes Bruder[404], Orit Halpern[405], and others, I find considerable proximity between the attribution of intelligence to entities like government and the recognition of certain machines as bearers of intelligence, which I contend constitutes a key condition of possibility for artificial intelligence's formulation as a managerial technology. Not only did this proximity anticipate the ongoing adoption of AI as a tool of government, but it also continues to inform the conceptualization and deployment of neural networks, whose highly distributed design has come to mirror the organizational ideals many governments have come to

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[401] Geoffrey Hinton, "Connectionist Learning Procedures," *Artificial Intelligence* 40 (1990): 185.
[402] e.g., Jon Guice, "Controversy and the State: Lord ARPA and Intelligent Computing," *Social Studies of Science* 28, no. 1 (1998): 103–38; Mikel Olazaran, "A Sociological Study of the Official History of the Perceptrons Controversy," *Social Studies of Science* 26, no. 3 (1996): 611–59.
[403] Pasquinelli, "How to Make a Class: Hayek's Neoliberalism and the Origins of Connectionism."
[404] Bruder and Halpern, "Optimal Brain Damage: Theorizing Our Nervous Present."
[405] Halpern, *Beautiful Data: A History of Vision and Reason Since 1945*.

pursue. Compared to other technologies with similar managerial import like computer simulation, whose legitimacy relied on their capacity to performatively participate in "future making and world crafting"[406], neural networks were for their part validated through their purported isomorphism with the Canadian state's distributed structure. As such, I understand neural networks' articulation as a managerial instrument as self-validating insofar as this model came to embody the same ideals and strategies of government deployed by the funding bodies sponsoring research in that field. In that regard, I not only claim that current conceptions of machine intelligence are inextricably linked to postwar ideas about "orderly, rational and efficient" government[407], but also suggest that changes in the regulation of communication, computing, and more recently AI closely map onto transformations in the very definition, practice, and organization of government.

But beyond this isomorphism, I contend that we can find traces of this proximity between conceptions of rational government and ideals of machine intelligence in the very structure of contemporary neural networks. While the previous sections documented the influence of new ideas about networks on the organization of labour in government settings, there is also a lot to be said about how the Canadian government, once understood as a network, framed the language of what neural networks were and could do. The latter is best exemplified by the evolution of Hinton's own conception of neural networks following his move to Canada and work with federal institutions. While initially concerned with neural networks' cognitive plausibility and the development of a theory of intelligence applicable to both humans and machines, Hinton gradually abandoned biological accuracy as a useful lens to both understand, and further refine, his model. CIFAR and the many royal commissions previously discussed had indeed already promoted a

[406] Jenny Andersson, *The Future of the World: Futurology, Futurists, and the Struggle for the Post-Cold War Imagination* (Oxford, UK: Oxford University Press, 2018), 6; see also Paul Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, MA: The MIT Press, 2010).
[407] e.g., Pelletier, *Computer/Communications Policy: A Position Statement by the Government of Canada*, 2.

vision of networks as a privileged model to organize both labour and government operations, but what Hinton did is translate this organizational understanding of government into a highly operational approach to machine intelligence. In all the use cases he explored with the support of Canadian funding bodies, Hinton did not so much attempt to fully automate government operations as streamline them in smaller, more standardized tasks that could be then fulfilled by untrained government workers. If his neural networks came to be recognized as the bearers of intelligence, it was then insofar as they raised the prospect of turning what was previously seen as skilled, professional work into mechanical and repetitive labour, over which so-called rational management could be more easily exercised. While initially concerned with emulating human intelligence, Hinton's neural networks thus gradually came to be deployed with the aim of doing away with the need for it.

The nuance between both postures is best expressed by the two main learning procedures Hinton developed during his career—namely, backpropagation[408] and his "greedy" learning algorithm[409]. While the former's introduction coincided with Hinton's initial appointment at CIFAR, the latter's development occurred when Hinton had already been appointed director of CIFAR's AI program and sat on several federal committees on AI regulation and procurement. In the case of backpropagation, Hinton's understanding of machine intelligence revolved on the idea the latter had to be closely modelled on human intelligence and that any empirical success a model might achieve shed little light on the nature and functions of intelligence if it wasn't biologically inspired. As mentioned earlier, backpropagation consisted in "repeatedly adjust[ing] the weights of the connections in the network"[410] until a desired output is produced. While successful at

[408] Rumelhart, Hinton, and Williams, "Learning Representations by Back-Propagating Errors."
[409] Geoffrey Hinton, Simon Osindero, and Yee-Whye Teh, "A Fast Learning Algorithm for Deep Belief Nets," *Neural Computation* 18 (2006): 1527–1554.
[410] Rumelhart, Hinton, and Williams, "Learning Representations by Back-Propagating Errors," 533.

training neural networks to perform simple tasks, this procedure did not represent for Hinton "a plausible model of learning"[411] insofar as it relied on a stochastic approach to set the value of each unit. What backpropagation did get right for him, however, was how the core of the computation performed by the brain occurred at the level of intermediary or hidden units "whose actual or desired states are not specified by the task"[412]. Compared to previous training methods, which required that the value of each unit be established by hand[413], backpropagation allowed to not only set these values automatically, but also increase the width and scale of neural networks, which was key for Hinton in developing neural networks that might eventually be able to reproduce the highly parallelized structure of the brain. Further emphasizing the need for software implemented neural networks to be designed on the model of biological ones, Hinton claimed that any breakthrough in AI was entirely dependent on further research into "how computation is organized in systems like the brain"[414], reaffirming the brain's status as the ultimate source of validation for AI research.

Twenty years later, however, after years of researching applications to be used in government and other institutional settings, Hinton introduced a new learning procedure which, in addition to producing neural networks with more depth, conveyed a new understanding of machine intelligence. Called the "greedy" learning algorithm, it was presented by Hinton not so much as a more comprehensive alternative to backpropagation but rather as a procedure especially well adapted to the type of increasingly specialized tasks that were expected from neural networks. In his words, the procedure boiled down to attributing "a different representation of the data," as opposed to all the data, to each unit and using their individual output as training data for subsequent

[411] Rumelhart, Hinton, and Williams, 536.
[412] Rumelhart, Hinton, and Williams, 533.
[413] e.g., Rosenblatt, "Principles of Neurodynamics: Perceptrons and the Theory of Brain Mechanisms."
[414] Hinton, "Connectionist Learning Procedures," 185.

layers[415]. Moving away from the brain as neural networks' structuring metaphor, the procedure aimed to emulate how organizations distribute knowledge and information among those who constitute it in a highly structured manner, in stark contrast with backpropagation's stochastic approach. If it were deemed "greedy," it was thus because it gave each unit the minimum amount of information it needed to function within the network, with Hinton casting any additional information they might be given as introducing needless noise. Moving away from his previous stance, Hinton then reconceived of his neural networks as closer to social systems organized on a distributed albeit purposefully managed model than to the brain or other biological entities. While more restricted in terms of the scope of their internal representations, the resulting neural networks were nevertheless deemed capable of developing highly specialized representations especially well adapted for the type of minute tasks intended for them. Shifting the emphasis from units to layers, and from width to depth, Hinton and his greedy algorithm then fostered a new emphasis on *deep* neural networks, but also *specialized* neural networks, whose perceived intelligence came to be more closely tied to their capacity to perform highly specific tasks than to acquire comprehensive representations.

But beyond such technical considerations, it is the whole of intelligence—if not more—that Hinton came to redefine in such operational terms with his new training algorithm. In a few short paragraphs concluding the piece, Hinton contended that the deep neural networks resulting from his "greedy" training procedure acquired internal representations that are so specialized and targeted in their scope that they basically "constitute[d] veridical perception"[416]. To support his point, Hinton tasked a neural network trained with his greedy procedure to classify hand-written numbers to perform the clerical task *par excellence*: inscribing numbers. Throughout the article,

[415] Hinton, Osindero, and Teh, "A Fast Learning Algorithm for Deep Belief Nets," 1535.
[416] Hinton, Osindero, and Teh, 1546.

various images of what seems to be carefully hand-drawn numbers, but are instead computer-generated pictures, are presented as proofs that neural networks trained with his method can achieve a human-like level of mastery of such minute tasks. Claiming that the impossibility to differentiate between actual hand-written numbers and his computer-generated ones proved that his neural network had internalized these numbers just like a human would, Hinton went as far as declaring that what his neural networks acquired during their training was in fact something even more human: namely, a mind. However unusual his use of the word might be, Hinton emphasized that it was "not intended to be metaphorical"[417] and instead claimed that tasking a neural network to generate such inscriptions was akin to "looking into the mind of [that] neural network"[418]. While this conflation might seem puzzling coming from a trained cognitive scientist, it nevertheless reflected the broader relocation of intelligence at the level of structures, operations, and processes that had animated his work for the past 20 years. Once modelled on the social structure of complex organizations, both intelligence and the mind itself came to be defined by the type of minute, operational tasks necessary to such organizations.

So far from completely dislocating his neural networks from their biological counterparts, Hinton instead reversed the relationship between the two by redefining the latter in terms of the former. Abandoning cognitive or biological plausibility in favour of empirical successes as neural networks' source of validation, Hinton redefined his model in terms of its capacity to perform certain tasks. By conflating machine intelligence with a capacity to break down tasks previously performed by trained workers, it is the whole of intelligence that Hinton recast as primarily operational in nature, reflecting the very priorities and concerns of the funding bodies sponsoring his work. Once conceived of as a faculty that could be isolated, externalized, and reproduced,

[417] Hinton, Osindero, and Teh, 1546.
[418] Hinton, Osindero, and Teh, 1545.

intelligence emerged as something that could be extracted from workers given the right structures and attributed to the very tools organizing their labour. While agnostic to the nature of mental states and intellectual faculties *per se*, this performative approach nevertheless redefined the mind around a highly operational worldview, to the point of reducing the latter to whatever tasks or functions fulfilled by neural networks. What the evolution, shift, and reorientation of Hinton's research highlights is then not how computer science provided the impulse, blueprint, or principles for this reorganization of work and redistribution of intelligence, but the exact opposite. Here represented by a set of research programs and reforms spearheaded by the Canadian state from the 1960s onward, it is this very organizational model—one anchored in structuralist ideas about rationality, control, and communication, highly algorithmic in nature and decentred from human intervention—which provided the larger backdrop for neural networks to appear as a promise approach to artificial intelligence.

As such, it is first and foremost as an organizational technology that neural networks' latest manifestation can be best understood, with the specific reorganization of labour it both required and promoted being symptomatic of, if not predicated on, Cold War ideas about distributed control and rational government. With AI now being a national priority for many governments including the Canadian federal government, we are witnessing a second structuralist, highly performative moment where a larger faith in technology's capacity to mediate and reorganize all spheres of human activity stands yet again as a full-on political epistemology. Since his election as prime minister in 2015, current Prime Minister Justin Trudeau stood out for his reforms dedicated to the pursuit of what he has come to call "Canadian AI." Advised by Hinton himself, who chairs on the council responsible for developing Canada's "long-term vision […] on AI both domestically and internationally"[419], Justin Trudeau promoted the sponsorship, regulation, and implementation of AI as a privileged means to not only improve and rationalize government processes, but also create pan-national prosperity and unity. Constituted as a revolutionary technology twice, first in the 1980s and then in the 2010s, AI then stands as an enduring site of technological, social, and national desire, where the prospect of greater government control, and greater control over government, converges with that of machine intelligence. Seen alongside one another, these two moments highlight the governmental, organizational, and managerial trajectory of neural networks, with the latter's re-articulation into an approach to machine intelligence testifying to AI's proximity with a certain rationalizing ethos mediating the attribution of intellectual potential to machines and structures. Seen in such terms, AI then refers as much to models like neural nets as to the organizational *a priori* which makes such models and their applications possible—an interpretation which not only exposes the disconnect between AI's social construction and political life, but also highlights how both ultimately enable, legitimize, and naturalize one another.

3.6 Conclusion

As discussed throughout this chapter, the fundamental problem to which neural networks' third and current iteration was developed to address was that of how best to organize and manage complex, distributed systems in order to restore and maintain a certain degree of control and oversight over them. While a wide range of organizations both public and private were confronted to this problem throughout the Cold War period, it was most strikingly experienced by the Government of Canada, for which it constituted a direct threat to its political survival. As a

[419] see Lisa Setlakwe, "Advice to the Deputy Minister: Teleconference Meeting with Government of Canada Advisory Council on Artificial Intelligence," in *ATIP Request #A-2019-00546* (Ottawa, Canada: Ministry of Innovation, Science, and Economic Development, 2019).

solution, various actors both within and outside the federal government articulated a broader vision of networks as a privileged model to organize the latter's ever-growing civil service and its various components, by turning their respective hierarchies into a more distributed albeit purposefully managed structure. Motivating the creation of various research programs and the adoption of several government reforms, this vision translated into the development of new tools and organizational models that specifically aimed to both reduce the government's reliance on skilled labour and increase its overall control over its operations. From the NRC's machine translation program to CIFAR's publicly funded AI program, the Government of Canada championned various attempts to break down its operations into standardized tasks that could be fulfilled by untrained and replaceable workers, over whom top-down management could be more easily exercised. As the culmination of these efforts, neural networks' third iteration was specifically designed to reorganize and streamline the work of mid-level, government clerks, who became both a source of inspiration for the articulation of new ideas about machine intelligence and the privileged target of technocratic attempts to do away with trained workers. More than their cognitive plausibility or even conceptual soundness, it was thus their very capacity to perform certain operationally relevant tasks that became the source of validation for neural networks' third and current form—a highly performative epistemology positing that the capacity to reproduce tasks fulfilled by intelligent agents was itself a sign of intelligence.

But while neural networks, just like Système-Q and Telidon before them, did succeed at delivering some of the basic results that were expected from them, there are few reasons to believe that they indeed resulted in, and were thus legitimized by, an increase in efficiency in the various government settings where they were adopted—on the contrary. For in parallel of all these attempts to technologically restore a certain degree of top-down oversight, there emerged a growing movement of contestation both within and outside the government, which claimed that these attempts led to more disorder than order within the Canadian civil service. By the end of the 1970s, this movement had grown so vocal that the government was forced by the official opposition to appoint yet another commission—the Royal Commission on Financial Management and Accountability—whose mandate consisted in evaluating the merit of the major reforms the government had undertaken in the previous two decades. In its final report, the commission paid especially close attention to the introduction of new tools and technologies in the Canadian public service and concluded that their adoption had led to "a failure to plan thoroughly at the top, [...] a consequent failure to budget rationally, and a confusion of responsibility for control and evaluation"[420]. Far from having improved government operations, these tools and reforms instead engendered a growing disconnect between the various levels of government by failing to facilitate the circulation of information from the bottom to the top of government and back. And yet, as documented throughout this chapter, these centralizing efforts continue for most of the 1980s and 1990s, raising the question of what exactly were these programs and reforms trying to achieve if not greater efficiency.

One of the most popular—and convincing—explanations that have been advanced is that it was the whole realm of rationality and management that underwent a profound transformation throughout the Cold War period, to the point of becoming altogether defined by such tools and reforms. The clearest formulation of this argument has been proposed by Paul Erikson and his colleagues who, in their account of Cold War rationality, highlight how the postwar period witnessed "the expansion of the domain of rationality at the expense of that of reason"[421], with

[420] Allen Lambert, *Royal Commission on Financial Management and Accountability: Final Report* (Ottawa, Canada: Privy Council Office, 1979), 68.
[421] Paul Erickson et al., *How Reason Almost Lost Its Mind: The Strange Career of Cold War Rationality* (Chicago, IL: University of Chicago Press, 2013), 2.

standardized procedures, communication technologies, and algorithmic systems displacing human judgment, experience, and reason as the main ideals around which the practice of government was organized. But more than that, I'd argue that this displacement was itself but a symptom of a broader phenomenon that is arguably one of the few things that unite each of neural networks' iterations—namely, a fundamental distrust of people. Starting with their initial formulation in the context of late 19th-century neurophysiology, neural networks were deployed to do away any form of human interpretation or judgment about the fundamental structures of life, by notably promoting a certain way of inscribing all knowledge about life onto life's material substrate. Similarly, neural networks' second iteration undermined mental patients' capacity to make sense of, and discuss, their own condition and aimed to replace all forms of psychotherapy by somatic lines of treatment. In their third iteration, finally, neural networks expanded this unwillingness to depend on people's knowledge and interpretations into an organizational principle, by recasting all forms of human expertise as a threat to the optimal organization of large social systems. In each of these cases, it was then a similar, almost irrational mistrust of people that animated not only neural networks' three formulations in the context of late 19th-century neurophysiology, postwar psychiatry, and late 20th-century computing research, but also the various calls for objectivity, efficiency, and optimization that came to be associated with them.

This similarity doesn't diminish the fundamental differences that remain between each of neural networks' formulations. As noted throughout this project, neural networks' three iterations not only referred to widely distinct objects, but also validated practices that were themselves hugely different. But what this mistrust of people shows is how neural networks' deployment has been systematically motivated by the broader project of reorganizing certain bodies—be they the literal bodies of dissected cadavers, the medicalized ones of psychiatric patients, or the devalued ones of workers—in order to reaffirm their assumed difference. In each case, neural networks were deployed to construct certain bodies as inferior, sick, or replaceable, while themselves coming to embody the same qualities—intelligent, self-guided, agential, etc.—as those attributed to the people who deployed them. These iterations' respective settings might differ just like their aim, but they nevertheless highlight how the recognition of certain subjects, structures, and machines as privileged bearers of intelligence was systematically predicated on the reconceptualization of other bodies as closer to machines than people. In short, what neural networks' various iterations show is then how the history of intelligence is basically that of its attribution to certain bodies over others, be it through the inscription of that difference onto these bodies or through its reification into machines and models modelled on them.

CONCLUSION—IN A COMPUTER SOMEWHERE, c. 2023

SIMPLE UNITS

AND NETWORKS

EVERYWHERE

```python
import numpy as np

class Perceptron:
  def __init__(self, num_inputs, learning_rate=0.1):
    self.weights = np.zeros(num_inputs + 1)
    self.learning_rate = learning_rate

  def predict(self, inputs):
    weighted_sum = np.dot(inputs, self.weights[1:]) + self.weights[0]
    return 1 if weighted_sum > 0 else 0

  def train(self, inputs, label):
    prediction = self.predict(inputs)
    error = label - prediction
    self.weights[1:] += self.learning_rate * error * inputs
    self.weights[0] += self.learning_rate * error
```

Figure 5. Script for a single-layer, perceptron style neural network in Python, coded by a multi-layer neural network (ChatGPT).

When reviewed alongside one another, the various practices and discourses surrounding neural networks' three main iterations in the context of 19th-century histology, wartime psychiatry, and late 20th-century computer science undermine the teleological narrative that has come to be associated with this model. Far from showing the gradual yet steady convergence of human and machine intelligence, these three episodes highlight how neural networks were deployed to not only answer widely different questions, but also manage, more than explain, the phenomena they aimed to theorize. In short, what bridges these three moments is a sustained investment in experimentation, which was manifested by the development of new standardized techniques to render brain tissues, bodies, and whole populations available to experimental manipulation. Under the pretense that "it seems best to handle even apparent continuities as some numbers of some little steps"[422], these techniques actively constituted the people they targeted as "little steps" that could be re-arranged and re-configured as to produce some desired output. Be it by reducing human difference to the configuration of nerve cells, pathological states to the passage of electric impulses, or complex social systems to the management of the individuals constituting them, these techniques specifically aimed to restore a certain degree of control in the face of colonial decline, deinstitutionalization, and bureaucratic mismanagement. As both the result of, and justification for, these various conflations, neural networks did not so much function as some abstract model of intelligence applicable to humans, machines, and even social systems. Instead, they stood as a complex experimental construct produced through the management of the various bodies marked as deviating from the idealized order they embodied—namely, a distributed albeit highly stratified one, conceived of in the image of interconnected neurons arranged into a dense, hierarchical network.

[422] McCulloch and Pfeiffer, "Of Digital Computers Called Brains," 368.

What neural networks' three main iterations point to therefore goes beyond the question of whether representing biological neurons as specialized units probabilistically linked together is biologically accurate, or even if neurology can provide a useful lens to understand mental states. Instead, what it shows is the recurrence, and repeated failure, of a certain way of not only reducing complex phenomena to locatable structures, but also constructing the latter as proxies for the former. This specific view indeed extends beyond neural networks, which, along with swarms[423], black boxes[424], and clouds[425], are only one of the many figures to reduce the emergent properties and functions exhibited by complex systems to the interactions among the individual components constituting them. As Alexander Galloway and Eugene Thacker point out, there is a broader tendency across "poetic, philosophical, and biological studies [… to ask] how does 'intelligent,' global organization emerges from a myriad of local, 'dumb' interactions"[426] and neural networks are only one of the many models to ask that question. But where neural networks differ from these other models is by the way they frame this question as the defining problem of biology if not life itself. Materialized through techniques such as silver staining and hygienic policies, brain lacerations and electroshock therapy, and finally programming and organizational reforms, neural networks captured brains, minds, and social systems alike as privileged manifestations of such structuralist views of organization, communication, and control. As such, their history is thus also that of the very conditions that were necessary for this question to be not only thinkable but also applicable to the whole of biology. Far from providing a definite answer to it, neural networks

[423] e.g., Jussi Parikka, *Insect Media: An Archaeology of Animals and Technology* (Minneapolis, MN: University of Minnesota Press, 2010); Georg Vrachliotis, "Popper's Mosquito Swarm: Architecture, Cybernetics and the Operationalization of Complexity," *European Review* 17, no. 2 (2009): 439–452.
[424] e.g., Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision"; Philipp von Hilgers, "The History Of The Black Box: The Clash Of A Thing And Its Concept," *Cultural Politics* 7, no. 1 (2011): 41–58.
[425] e.g., Tung-Hui Hu, *A Prehistory of the Cloud* (Cambridge, MA: The MIT Press, 2015); John Durham Peters, *The Marvelous Clouds: Toward a Philosophy of Elemental Media* (Chicago, IL: University of Chicago Press, 2015).
[426] Alexander Galloway and Eugene Thacker, *The Exploit* (Minneapolis, MN: University of Minnesota Press, 2007), 67.

introduced the necessary level of indeterminacy to allow for the brain, the mind, and human sociability to be reconceived of in terms of simple units interacting together, to the point of neural networks no longer appearing as a concept or model but instead as an empirical fact.

This nuance is key as it turns on its head how my protagonists viewed the objects and subjects they attended to. While Ramón y Cajal conceived of the organization of nerve cells as a reflection of how both individuals and whole societies partake "in the struggle for [...] organic evolution"[427], McCulloch for his part approached his psychiatric patients as privileged case studies to demonstrate the neurophysiological basis of the mind[428]. In both cases, my protagonists approached their subjects as model organisms for the study of the broader phenomena they aimed to model. But while model organisms are generally understood as stand-ins for[429], or fragments of[430], the broader phenomena they are supposed to capture to the point of altogether disappearing behind the latter[431], my protagonists' subjects were instead selected for the way they deviated from the principles neural networks embodied. From Ramón y Cajal's anatomical work with cadavers and McCulloch's clinical trials with schizophrenic patients to Hinton's efforts to automate the work of low-ranking clerks, the history of neural networks is populated by human figures whose mobilization within the experimental settings of histology, psychiatry, and computer science aimed to restore a certain degree of control over them. To do so, my protagonists strived to organize their

[427] Ramón y Cajal and Craigie (translator), *Recollections of My Life*, 225.
[428] e.g., McCulloch and Pitts, "A Logical Calculus of the Ideas Immanent in Nervous Activity"; Ladislas Meduna and Warren McCulloch, "The Modern Concept of Schizophrenia," *Medical Clinics of North America* 29, no. 1 (1945): 147–64.
[429] e.g., Rachel Ankeny and Sabina Leonelli, *Model Organisms* (Cambridge, UK: Cambridge University Press, 2020).
[430] e.g., Evelyn Fox Keller, "Models of and Models for: Theory and Practice in Contemporary Biology," *Philosophy of Science* 67 (2000): S72–86.
[431] see also Bonnie Clause, "The Wistar Rat as a Right Choice: Establishing Mammalian Standards and the Ideal of a Standardized Mammal," *Journal of the History of Biology* 26, no. 2 (1993): 329–49; Robert Kohler, *Lords of the Fly: Drosophila Genetics and the Experimental Life* (Chicago, IL: University of Chicago Press, 1994); Karen Rader, *Making Mice: Standardizing Animals for American Biomedical Research, 1900-1955* (Princeton, NJ: Princeton University Press, 2004).

subjects in the image of neural networks, namely, as simple units that could be intervened on, and managed, by mediating the type of relationships they develop both among themselves and with others. In that sense, for the way they promoted neurality as a form in, and an organizing principle of, the world, I propose to understand neural networks not as a model but as a medium—one communicating a view of the human biology, psychology, and sociality that is not only highly technologized, but also profoundly normative in nature.

Building on Clifford Siskin's definition of mediation as "a form that works physically in the world to mediate our efforts to know it"[432], I propose to understand Ramón y Cajal's, McCulloch's, and Hinton's various formulations—and inscriptions—of neural networks as representative of a subset of media I tentatively term *neural media*. With it, I aim to theorize the various constructs deployed by my protagonists to not only promote "neurality" as a form, but also naturalize it as a biological given. Various terms such as "protocol"[433], "format"[434], and "script"[435] have already been introduced to theorize how media technologies enforce norms and standards onto the bodies they are applied to, but they do not capture cases when rendering bodies available to such norms and standards is itself the outcome of mediation. For in each of their iterations, neural networks were not only inscribed onto certain bodies through various experimental techniques, but also used to capture these bodies as privileged objects of experimentation to begin with. Each of neural networks' iterations epitomized a subset of experimental systems which, throughout the 20th century, conflated communication with structure, meaning with medium, and

[432] Clifford Siskin, *System: The Shaping of Modern Knowledge* (Cambridge, MA: The MIT Press, 2016), 1.
[433] Lisa Gitelman, *Always Already New: Media, History, and the Data of Culture* (Cambridge, MA: The MIT Press, 2006).
[434] Jonathan Sterne, *MP3: The Meaning of a Format* (Durham, NC: Duke University Press, 2012).
[435] Bernard Geoghegan, "Orientalism and Informatics: Alterity from the ChessPlaying Turk to Amazon's Mechanical Turk," *Ex-Position* 43 (2020): 45–90.

cognition with neurophysiology. Beyond neural networks, other media such as neurohacking[436], "smart" devices[437], or even internet networks[438] qualify as part of this subset for the way they similarly deploy the figure of the neuron—or of the neural-like network—to justify their interventions. In all such cases, it is the notion of the neurality that is itself the outcome of the gradual abstraction of the body into brains, minds, and ultimately intelligence *tout court*, which all provide increasingly intricate proxies for phenomena both social and psychological that otherwise evade both experimental and technological mediation.

From Ramón y Cajal's racialized brain and McCulloch's diseased mind all the way to Hinton's networked intelligence, neural networks mediated how various bodies were perceived, known, and made use of. Once recast in racial terms, the brain was used to justify the subjection of various populations to new forms of colonial management; once recognized as susceptible to illness and disease, the mind allowed psychiatrists to capture certain bodies as the privileged targets of highly intrusive forms of clinical treatment; once conceived of as the outcome of a certain way of organizing limited resources into networks, intelligence became a privileged lens to manage workers and devalue the situated knowledge they held. In all these cases, brains, minds, and intelligence were not only made to convey specific meanings and enable certain practices, but also deployed to affirm the primacy of the neural domain across a variety of fields, time periods, and national settings. In that context, what neural media theorizes is how the very notion of neurality is itself a highly performative construct, which promotes organizational principles such

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436 Aleena Chia, "Oneirogenic Innovation in Consciousness Hacking," in *Technopharmacology* (Minneapolis, MN: University of Minnesota Press, 2022), 55–88.

437 Joshua Neves, "The Internet of Things and People," in *Technopharmacology* (Minneapolis, MN: University of Minnesota Press, 2022), 89–119.

438 Urs Stäheli, "Undoing Networks," in *Undoing Networks* (Minneapolis, MN: University of Minnesota Press, 2020), 1–30.

as atomization, interdependence, and mediation at the same time as it frames them as biologically given.

This reading builds on various accounts of how conceptions of machine intelligence have been historically associated with the management of workers[439] but more specifically highlights how neurality itself has come to stand for a full-on organizational technology rendering the bodies it is applied to available to various managerial practices. When analyzed historically, from their inscription onto brain tissues to their transposition into electric circuits and later software, neural networks highlight how the convergence between the human body and technology into a broader theory of organization is not so much the end goal of neuro- and computer science as their starting point. What the notion of neural media shows is how the very idea of neurality is far from being natural and self-evident and is instead produced and sustained through highly situated practices and mediations which endow neurality with various embodied and embedded forms. That atomization, interdependence, and mediation are now so closely associated with the structure of the brain is but the outcome of sustained efforts to project onto human biology principles, processes, and structures inherited from colonial hygiene, somatic approaches to psychiatric treatment, and technocratic views of public management. Once reduced to its structure, the brain became a powerful device to naturalize a vision of organization as the main determinants of systems and thus a privileged means through which certain social orders could be (re)produced. If simple units and interconnected networks suddenly proliferate when neural networks are involved, it is not so much because of their universality as structures but instead because of the performative

[439] see Ranjodh Dhaliwal, "The Cyber-Homunculus: On Race and Labor in Plans for Computation," *Configurations* 30, no. 4 (2022): 377–409; Barbara Garson, *The Electronic Sweatshop: How Computers Are Transforming the Office of the Future* (London, UK: Penguin Books, 1989); Simon Schaffer, "Babbage's Intelligence: Calculating Engines and the Factory System," *Critical Inquiry* 21, no. 1 (1994): 203–27.

nature of neurality itself, which mediates how complex biological, psychological, and social systems are made legible as, and actively shaped into, such structures.

When considered in relation to neural networks' trajectory across neurophysiology, psychiatry, and computer science, what the notion of neural media shows is then how the history of artificial intelligence (AI) is essentially that of mediating who or what is recognized as the bearer of intelligence. In each of neural networks' iterations, intelligence has been systematically constructed as a faculty unevenly distributed. Once reduced to a purely structural basis, intelligence became a quality inherent to those who embody the right structures, be they humans or machines. Through the lens of neural networks, the type of intelligence involved in both human and machine intelligence is one completely emptied out of its content, context, and conditions, but which simultaneously mirrors in its form and functions the highly hierarchical worldview that underpins its attribution to some versus others. That AI participates so actively in perpetuating historical assumptions about racial difference, the normal and the pathological, and divisions between intelligent work and mechanical labour is but a reflection of how intelligence has been constructed as held by certain people more than others, with all its iterations both biological and computational being at the centre of broader structures of power that maintain that same uneven distribution of intellectual potential. What neural media points to is then how the very attribution of intelligence is actively mediated by various technologies that naturalize certain bodies as its privileged bearers while obfuscating the politics behind that attribution. More than a century after neurons' initial introduction as intelligence's fundamental mediator, it is now the architecture of biologically inspired learning machines (see Figure 5) that fulfills the function of communicating that technologized view of human neurology, pointing to the persistence of neurality itself as both an artefact of, and an artifice for, the attribution of intelligence.

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