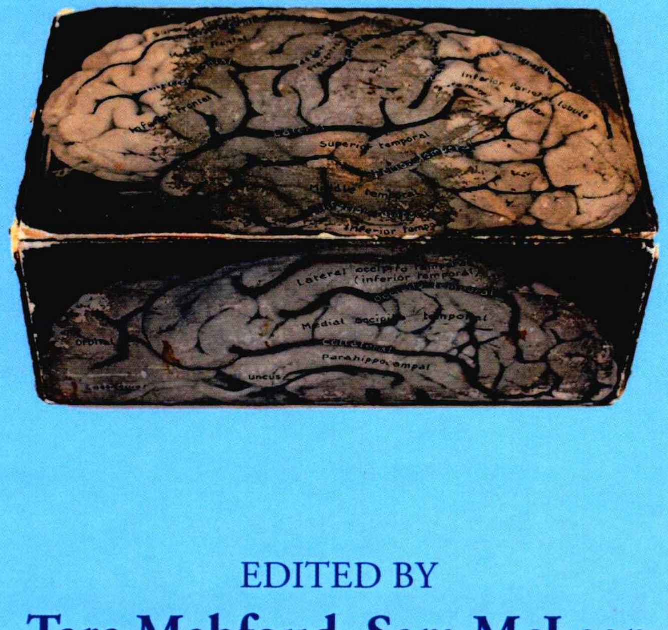
PROGRESS IN
BRAIN RESEARCH

233

Vital Models

The Making and Use of Models in the Brain Sciences



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Progress in Brain Research
Volume 233

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525 B Street, Suite 1800, San Diego, CA 92101-4495, United States
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom
125 London Wall, London, EC2Y 5AS, United Kingdom

First edition 2017

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ISBN: 978-0-12-804215-1
ISSN: 0079-6123

For information on all Academic Press publications
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Publisher: Zoe Kruze
Acquisition Editor: Kirsten Shankland
Editorial Project Manager: Ana Claudia Garcia
Production Project Manager: Magesh Kumar Mahalingam
Cover Designer: Greg Harris

Typeset by SPi Global, India

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Preface

In the contemporary neurosciences, particularly with the advent of "big science" projects like the Human Brain Project in the European Union and the BRAIN Initiative in the United States, brain models are often presented as a powerful way to move forward understandings of the brain. For example, the Human Brain Project claims that "Empirical research will enable the formulation of multi-scale theories and predictive neuroinformatics by modeling and simulation to identify organizational principles of spatial and temporal brain architecture" (Amunts et al., 2016). The US BRAIN Initiative seeks to "shed light on the complex links between brain function and behavior, incorporating new theories and computational models."

Other big neuroscience projects in China, Japan, Russia, Israel, and elsewhere also have modeling as one of their main methods and objectives. It is through brain models, many argue, that an integrated understanding of the different scales or levels of the brain that neuroscientists usually study in isolation—genes, molecules, neurons, networks, brain regions, all the way to the whole brain—can be achieved, leading to better treatment of brain disorders and illnesses (Grillner et al., 2016). In order for more complex models to be built, many scientists claim that advances in computing need to take place, alongside advances in brain imaging technologies that can reveal greater and more precise details of different structural and functional processes that the models need if they are to be effective.

Despite this strong computational current in contemporary neuroscientific modeling practices, Abi-Rached and Rose remind us that "brain model" is an umbrella term that includes many different kinds of models of different temporal and spatial scales, that brain models are not just computational, and that the use of models to study brains is anything but new (2013, pp. 92–101). Indeed, it was in the 1800s that wax anatomical and pathological models of whole brains were made to assist surgery and teaching (Alberti, 2009) and when phrenology models claiming to represent the links between behavior and brain gained prominence (McLaren, 1981). In the early 1900s electrophysiological models—such as Lapique's integrate and fire model from 1907, and the Hodgkin–Huxley model from 1952—were developed to explain the behavior of nerve cells (Brunel and van Rossum, 2007; Craver, 2008). The history of cybernetics can be traced back to the 1940s (Pickering, 2010), and simulation models to the period after the Second World War (Keller, 2002). More recent digital brain models, like the Talairach Atlas, were developed in the 1980s (Beaulieu, 2002) at a time when model organisms were also gaining prominence in the biological sciences (Ankeny and Leonelli, 2011).

As the epistemic and experimental value of "the brain" has risen in the intellectual and social imagination, life and natural scientists, social scientists, and humanities scholars have increasingly converged on what we might term the vital brain. This is a shared understanding of brains as complex open systems, shaped by constant interactions between nervous systems bodies, as well as social and cultural processes (Abi-Rached and Rose, 2013; Damasio, 1995; DeLanda, 2015; Wilson, 2004).

It follows, therefore, that the most scientifically useful, medically efficacious, and conceptually compelling brain models will be those most capable of expressing these complex and dynamic processes.

1 VITAL MODELS

The papers in this volume converge on one key argument: brain models that model the brain in isolation, separate from the wider nervous system and body on the one hand, and from societies and cultures on the other will always deliver limited practical and intellectual benefits. This argument has been made by social scientists (Abi-Rached and Rose, 2013; Choudhury and Slaby, 2011; Martin, 2000; Rapp, 2011) since at least the 1990s, when the neurosciences started to displace the behavioral sciences as the dominant system of thought and mode of experimentation used to determine and examine human behavior (Gazzaniga, 2008; LeDoux, 1999; Mandler, 2011; Squire and Kandel, 2008). It is also necessary to recognize that scientific explanations are never context free: they are always located in, and shaped by, the specific historical, political, economic, and social contexts within which they are proposed and developed (Cohn, 2008; Dumit, 2004; Knorr Cetina, 1999; Latour and Woolgar, 1987; Lynch, 1985; Roepstroff, 2002).

In order to connect models of brains with the bodies and the worlds they inhabit we introduce the concept of "vital models." As we will see in the chapters throughout this volume, models are vital in three ways. First, we acknowledge that models are vital to neuroscientific practices in that they have been an essential medium through which scientists seek to know and understand the workings of human and animal brains. We also acknowledge that models are necessarily reductive—because models can never capture everything, there are always decisions and debates over what elements in a given system are vital to model and necessary to its functioning (Cartwright, 1983; Keller, 2010). Second, models are vital because they have a lively "social life" (Appadurai, 1988). Models do things in the world: they have social, economic, and political functions (not just scientific), they are never static nor stable, are often mobile and disruptive, and are always embedded within the social worlds of the scientists that make and use them. Third, models are vital because they are expressions of life. Within the neurosciences, they are designed and built in order to capture, mimic, or reproduce the behavior of the vital brains of living organisms.

We argue that brain models will be fundamentally flawed if they fail to grasp the vitality of their object—the brain. But as Greco (2005) rightly points out, given the sustained critique of vitalism, particularly in the wake of 20th-century developments in physics and molecular biology (Crick, 1982; Jacob, 1973; Prigogine and Stengers, 1984), it is important to be clear what we mean by vitality. We do not wish to invoke some kind of mysterious immaterial force, but to insist that properties of animate rather than inanimate matter are emergent from the particular form of organization of material elements that constitutes living organisms, which are shaped by time and space, and inescapably embedded in transactions with their internal and external environment. Hence, if one is going to understand the vital properties of organisms, one has to understand living organisms in terms of the continual transactions between nervous systems, bodies, and the physical and social worlds within which they exist.

Yet, as we will see in the following chapters, the majority of brain modeling projects assume that the limits of the fleshly thing to be modeled are defined by the limits of the brain—indeed they only rarely even locate that brain within the rest of the organisms' nervous system, let alone the hormonal and other physiological circuits with which that brain is indissociably linked. Further, the surfaces of the body, let alone the skull, do not delimit the boundaries of "the brain"—animal or human. To that extent, physician, historian, and philosopher of medicine and science, George Canguilhem argued (2007) that we are faced with a tension between two different ways of thinking of living organisms: to think of them as machines, whose operation can be understood in terms of "mechanistic" connections between its parts; or to think of living organisms as complex wholes with emergent properties that are inseparable from their environment, and where, indeed, those emergent properties themselves shape and reshape the activities and capacities of their component parts.

However, while Canguilhem retained the division of "machine and organism," and thereby maintained an ontological, even normative distinction between the vital and the artificial, we insist on the value of another kind of difference closer to our conception of vital models. The most vital brain models might well be 'artificial' and simulated, and almost certainly less dependent on correlations of life and purity that often haunt critiques of machines and technological innovation in the social sciences and humanities (see Deleuze and Guattari, 1987; Haraway, 1997). This is the difference between living organisms as "closed systems" understood in terms of "mechanistic" connections between their parts, and holistic "open systems" with emergent properties inseparable from their environment. Indeed, those emergent properties themselves shape and reshape the activities and capacities of their component parts. As contributions in this volume show, this conceptual difference (between closed–open systems) has material and practical effects for the kinds of brain models that can conceivably be designed and generated by neuroscientists. For if vital brains and nervous systems like all living organisms are "open" and changing, in the process of becoming more complex, models of them are necessarily incomplete.

How we think of this relationship—of the ways that organisms shape and are shaped by their environments—has implications for how we as human beings live and intervene in one another's lives (Myers, 2015; Rees, 2016; Rose, 2010). Scientific models, philosopher Ian Hacking urged us to see (1983), do not merely "represent" things they are designed to explain, they produce them. They are, he argues, "interventions" in life and nature. There are, therefore, both scientific and ethical imperatives to consider the implications of the assumptions brain models make of how living beings are connected (or not) with their environments.

As social scientists, we are also interested in the vitality of models because we can learn a lot about scientific cultures and their epistemologies from studying the ways that models are made, the beliefs they embody, and the practices within which they are utilized (see De Chadarevian and Hopwood, 2004). As the chapters in this volume demonstrate, the relationships of models to their referents are often metaphorical in nature. In the neurosciences, models often embody historically and socially shaped metaphors about the brain and its distinct capacities: attention and perception, emotion, and volition. Our aim here is not to argue "against models" because of their embeddedness or their "artificiality." Instead, we are arguing that it is important that brain modelers are aware of the epistemic and normative assumptions and presuppositions embodied in the models they create, and that those who use these brain models are similarly cognizant of their social, cultural, political, and ethical premises and implications.

We close the volume by asking whether, and how, models can be vital in the three ways we have put forward? How can models capture the vitality of living organisms and their transactions with their environments? How do models produce the life they intervene in? How might models capture the lively social lives of embodied brains? And what of the capacity of models to disrupt established ways of thinking about the kinds of human animals we have become? While models must simplify, how can this be done while remembering Claude Bernard's caution from his 1865 *Introduction to the Study of Experimental Medicine*:

> *Physiologists and physicians must never forget that a living being is an organism with its own individuality. We really must learn, then, that if we break up a living organism by isolating its different parts, it is only for the sake of ease in experimental analysis and by no means in order to conceive them separately. Indeed when we wish to ascribe to a physiological quality its value and true significance, we must always refer it to this whole and draw our final conclusion only in relation to its effects in the whole (Bernard, 1865, p. 88).*

If, as we believe, a living organism is inseparable from its location in time (the time of evolution, the time of development, the time of its existence) and space (the space mapped by its incessant transactions with other organisms and with its environment), then we must recognize this as fundamental for any vital model aiming to advance knowledge of how humans and other animals think, live, and behave. This is especially the case for models in neuroscience seeking to play a part in the translation from the lab to the clinic and the world–for example, those designed to shape interventions into human mental disorders, or psychiatric and neurodegenerative conditions. Studies from the social sciences, exploring the making and using of models within their political, social, and economic context, can and should help in the difficult task of making models that can more adequately capture the constitutive vitality of their objects.

2 THE CHAPTERS

In Chapter 1, Cornelius Borck develops the concept of "vital abstractions" to argue that abstractions are fundamental to research practices. When scientists do not take the context of the brain into account, this is a result of the media and instruments used throughout the research process and what these can capture, rather than the disinterest or negligence of the scientists themselves. Reflecting on the impact of the effects of WWII on developments in the neurosciences, and the ensuing entanglements between computers and brain models, Borck argues that while cybernetic brain models certainly abstracted the brain from both its biological and social context, the computer also enabled thinking and understanding the brain as a living entity. He goes back to the beginnings of cybernetics in the 1940s and reflects on Grey Walter's pioneering work with electroencephalography (EEG) and the excitement at the time over how this new technology could enable visualizing "The Living Brain"—the title of Walter's seminal book. The "vital abstractions" of EEG, Borck argues, are however different from what he calls the "concrete images" of functional magnetic resonance imaging (fMRI). While fMRI reveals images of structures and substrates, EEG held the potential for visualizing function.

In Chapter 2, the metaphor of visualization emerges in another context. Lara Keuck presents a new perspective on Alois Alzheimer and his place in an important yet under investigated episode in the history of neurology and psychiatry. With the support of unpublished lecture materials and notes, the chapter explores what Keuck terms the "making of the normal and the pathological brain." The chapter discloses the epistemological and methodological assumptions inherent in Alzheimer's treatment of the brains of deceased patients as technologically mediated neuropathological objects. For Alzheimer, they provide "pictures" of pathological processes and better clinical diagnosis. His argument was that the ascertainment of anatomical differences can guide the clinical gaze to look for differences in the living patient. Cortex pathology, not brain localization, should have defined the scientific development of neurological and psychiatric research. Keuck provides evidence for the necessity of making the conceptual assumptions of neuroscientific models explicit. Many of the issues that concerned Alzheimer—the representativeness yet artificiality of brain slices, and the necessity yet difficulty to conceive normal brains to compare the pathological ones with—have become fundamental, and often black-boxed, in more recent neuroscientific models of the brain.

In Chapter 3, the potential and possibility of vital brain models are positioned in an analysis of modeling psychosis and consciousness. Drawing on historical work and ethnographic fieldwork in neuroscience laboratories, Nicolas Langlitz's contribution develops a conceptual distinction between two 'ideal types'—transparent models and opaque models. This distinction is then used to shed light on a problem within brain modeling: how a complex and ill-understood mind-brain state can be used to explain or understand another complex and ill-understood mind-brain state. The examples discussed include hallucinogen intoxication and dreaming as models for psychosis and consciousness, respectively. The author concludes with a discussion on the following question: if the function of "opaque" models is not to represent a brain state, then what other social, political, and economic functions do these models have?

At a time when computational language seems to dominate discussions on brain modeling, it is important to remember that the computer and its information processing capabilities have not always been uncontested metaphors for the mind. In Chapter 4, Max Stadler argues that in the 1970s and 1980s, the "classic" computer metaphor that was dominant during the cybernetic era began to fall apart. In drawing on the wave of anticomputer sentiments caused by office automation, Stadler shows how beginning in the mid-1970s there were sustained efforts to demonstrate that the human mind was indeed *unlike* the logical, rule-based, information processor model of the mind and intelligence that inspired the founders of what we now know as the cognitive sciences. Whereas the "role model" cognitive agent of the 1950s and 1960s mind was typically men engaged in abstract "high-level" thinking like solving mathematical problems, the paradigmatic cognitive pursuit of the 1970s mind was "everyday activity." This posited intelligence as something tacit and implicit, sensory, distributed, and involving tools as extensions of the human body. In the 1970s and 1980s this model of a "cognitive agent" as embodied and embedded, argues Stadler, replaced the "problem solver" model of cognition of the 1950s and 1960s. Computers came to be seen as tools rather than metaphors, as aids to rather than explanations of human cognition, precisely because of the introduction of computers to everyday life in the postindustrial period. Stadler shows how the "embedded and embodied" model of the mind became a model of the computer "user" within the context of ergonomics research. It was this shift that enabled the continuing debates in the 1980s and 1990s within the field of AI to consider human intelligence as situated, bodily, and distributed.

In Chapter 5, Johannes Bruder takes research into artificial and human intelligence in another direction, raising questions about the vitality of abstract, artificial brain models. Contemporary brain modeling practices are argued to be the product of complex "entanglements" between AI, data science, and neuroimaging; entanglements made possible by state-of-the-art brain modeling technologies such as Google's AlphaGo algorithm of neural nets that is traced back to earlier neuroscientific models of episodic memory and imagination. Bruder argues that contemporary conceptions of intelligence—what the author terms "infrastructural intelligence"—can profitably be understood against the backdrop of developments central to the emergence of neuroimaging research since the early 2000s. Two developments are emphasized: the creation of the "default mode network" now used to shape research design in the neurosciences and the arrival of a new species of researcher in neuroscientific laboratories, the "data scientist" who manages the data generated by experiments. These developments, the author argues, have significant implications for how we think about the brain, and how neuroscientists can model vital brains. The shift toward converting data models into models of brain function (and vice versa) holds the possibility of modeling the brain as an integrated, dynamic system, rather than a set of static brain regions waiting to be "mapped."

In Chapter 6, Maria Serban critically assesses the claims made by computational neuroscientists about how and whether neural simulations can help to understand the brain. Serban distinguishes between two different types of applications of large-scale neural simulation as a methodology in the neurosciences: model-oriented and data-oriented applications. The chapter reviews the methodology of computer simulation more broadly and then moves on to an analysis of three large-scale neural simulation projects: the Blue Brain Project's simulation of a rat cortical column, Izhikevich and Edelman's simulation of a mammalian thalamocortical system, and the Cognitive Computation Project. Serban argues that any assessment of the claims made in these projects should take account of the applications of these simulations and how well the verification and validation processes support these intended uses and applications. Acknowledging that all simulation projects have trade-offs, the evaluation schema Serban introduces can help to achieve a more balanced assessment of large-scale simulation studies.

In Chapter 7, Haueis and Slaby provide a critical perspective on the role of connectomes in neuroscientific practice. From the outset they inform us of the meaning of the term "connectome"—it refers to a "complete map of neural connections in a nervous system of a given species." For the authors, this amounts to an unfulfillable promise with important scientific, philosophical, and social implications for brain models, and what they view as the broader neuroscientific program of research. These implications are examined in two parts. The epistemic norms of connectome research are explored, before being situated in a social and political history of neuroscientific practices. Their analysis arrives at two far-reaching contentions that demonstrate the vitality of brain models, as we understand them. The first is that the notion of connectomes as "complete descriptions" is misguided. They take concepts from Rachel Ankeny (descriptive models) and Jorg-Hans Rheinberger (epistemic things) and combine them to establish why connectomes are necessarily incomplete, resistant to stabilization and representation (Rheinberger, 1997). Any vital models of connectomes are open systems; they are defined by what is not yet known—they are "constitutively epistemic objects." The second refers to the social and political import of connectomic research, and the ambition and promise of "complete descriptions" of neural connections. Using the metaphor of "networks" they draw our attention to the complex social lives of neuroscientific models. To what extent do connectomic models of the "brain as network" embody, or perhaps even shape, the social and cultural milieu in which they are produced and circulated? Might they be ciphers of the "networked sociality" of the worlds we now live in? Or scientific vehicles of political and economic ideology?

In Chapter 8, Turner and De Haan provide a conclusion to this exploration of vital models in the contemporary brain sciences. They address many of the issues, problems, and questions raised throughout this volume. Based on a thorough review of the state of research on systems and cellular neuroscience, the authors make two main contributions. Having investigated significant barriers preventing the construction of testable mechanistic models, they then provide neuroscientists with a rigorous framework for assessing the validity of models of brain function. There is a problem, Turner and De Haan argue: Neuroscientific research at the levels of cells and systems continues to proliferate at an extraordinary speed, made possible by eye-catching innovations in scientific and medical technology. However, signs of progress in psychiatric medicine are difficult to discern at best, and the scientific status of cognitive psychology remains highly contested. This gap reflects two primary problems: What Turner and De Haan describe as "careless analysis" and "under-powered experiments." The authors respond to this context by exploring the potential of new developments in neuroimaging research. They argue that rigorous data-driven experiments and analysis of ultra-high-field MRI may "bridge the cellular and systems levels" with significant practical benefits for psychological research and psychiatric medicine. Vital brain models, Turner and De Haan show, are those that are experimentally innovative, analytically rich, and culturally informed.

To conclude, these chapters demonstrate how brain models are vital in the three senses of the term; models are vital to neuroscientific practices, they are vital in the sense that they have social, political and economic functions and implications, and they are vital because they are built to model the vitality of the brain. We hope that this volume will contribute to the literature on models in social science and philosophy, specifically in its analysis of how models are made and used in the neurosciences, and that the ideas in the chapters might provide inspiration to neuroscientists who are interested in modeling brains as entities embodied in living organisms and embedded in political, economic, and social worlds.

ACKNOWLEDGMENTS

The ideas expressed in this preface and the chapters themselves have come out of the workshop "Vital Brains: The Making and Use of Models in Neuroscience" held on April 7–8, 2016 at the Free University of Berlin and organized by the editors of this volume in collaboration with Philipp Haueis and Jan Slaby from the Critical Neuroscience network. We would like to acknowledge the Independent Social Research Foundation, the King's Interdisciplinary Social Science Doctoral Training Center, and the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement number 720270 (HBP SGA1) for making the workshop and resulting publication possible.

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