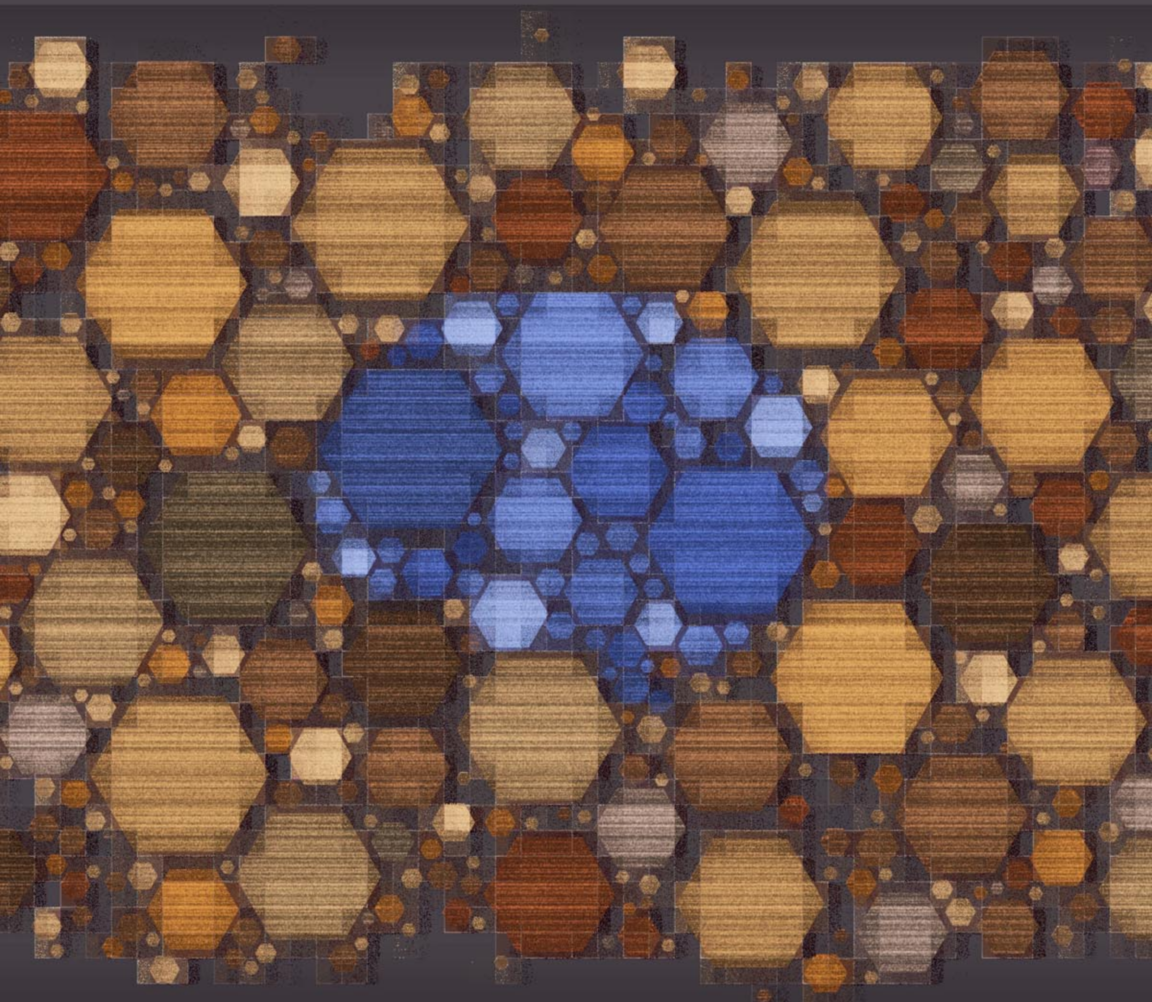
NEUROPROSTHETIC SUPERSYSTEMS ARCHITECTURE



Matthew E. Gladden

Neuroprosthetic Supersystems Architecture

Considerations for the Design and Management of Neurocybernetically Augmented Organizations

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Neuroprosthetic Supersystems Architecture: Considerations for the Design and Management of Neurocybernetically Augmented Organizations (First Edition)

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For all those working to design new interfaces with technology
That respect human dignity and empower human creativity

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Preface

This volume emerged from a project investigating the implications of posthumanizing neuroprosthetics for organizational enterprise architecture that was undertaken at the Institute of Computer Science of the Polish Academy of Sciences in 2015 and 2016 under the title of "Enterprise Architecture for Neurocybernetically Augmented Organizational Systems: The Impact of Posthuman Neuroprosthetics on the Creation of Strategic, Structural, Functional, Technological, and Sociocultural Alignment." This text represents a significant expansion of that work; in particular, it explores in greater depth the converging characteristics of human agents and electronic information systems that result from the growing use of advanced neuroprostheses, the role of military organizations as early adopters of posthumanizing neuroprosthetic technologies, and the use of network topology as a conceptual tool for designing and analyzing the architectures of neuroprosthetic supersystems. I offer my heartfelt thanks to Serge Pukas, Paulina Krystosiak, Robert Pająk, Jacek Koronacki, and everyone affiliated with the Institute of Computer Science for their encouragement and support of my research.

This book also draws on a number of my other previously published texts and conference presentations relating to various aspects of advanced neuroprosthetics and the anticipated organizational and social impacts of such technologies. In particular, I have drawn material from earlier works such as *The Handbook of Information Security for Advanced Neuroprosthetics* (2015); "Utopias and Dystopias as Cybernetic Information Systems: Envisioning the Posthuman Neuropolity" (2015); "Cybershells, Shapeshifting, and Neuroprosthetics: Video Games as Tools for Posthuman 'Body Schema (Re)Engineering'" (2015); "Implantable Computers and Information Security: A Managerial Perspective" (2016); *Sapient Circuits and Digitalized Flesh: The Organization as Locus of Technological Posthumanization* (2016); and "Neural Implants as Gateways to Digital-Physical Ecosystems and Posthuman Socioeconomic Interaction" (2016). Details regarding these works and their specific contribution to this text can be found in this book's bibliography and footnotes.

I am thankful to the faculty, staff, and students of the universities and other research institutions at whose conferences such material was first presented, including those of the Jagiellonian University, the Warsaw University of Technology, the University of Silesia in Katowice, the Centrum Informacji Naukowej i Biblioteka Akademicka (CINiBA) in Katowice, the Faculty of Humanities of the AGH University of Science and Technology, the Facta Ficta Research Centre, the Digital Economy Lab of the University of Warsaw, and the EuroMed Research Business Institute. In particular, I offer my deep gratitude to Krzysztof Maj, Ksenia Olkusz, Magdalena Szczepocka, Natalia Juchniewicz, and Renata Włoch. I am especially grateful to those scholars exploring the social and organizational implications of posthumanizing technologies whom I have had the opportunity to hear present their research and with whom I have enjoyed valuable conversations about these topics – especially Bartosz Kłoda-Staniecko, Agata Kowalewska, Krzysztof Maj, and Magdalena Szczepocka. I am also thankful to Paweł Urbański for sharing his expertise in the field of enterprise architecture through a number of helpful conversations.

As always, I am indebted to my parents, my brother, and other relatives, friends, and colleagues for the support that they have provided me in my research, and I offer my heartfelt thanks to my wife for her insightful counsel, friendship, and continual encouragement. The individuals mentioned above – along with many other conference attendees and anonymous reviewers who have provided feedback on my texts – have contributed much to the development of whatever value this book might hold. Those flaws that the book still possesses after their helpful input are my responsibility alone.

Matthew E. Gladden

Pruszków, December 6, 2016

Introduction

The Nature of Neuroprosthetic Supersystems Architecture

From Neuroprosthetic Devices to Neuroprosthetic Supersystems

This volume is a resource for the design and analysis of *neuroprosthetic supersystems,* which can be defined as organizations – either small or large, simple or complex – whose human members have been neuroprosthetically augmented. Such supersystems must be distinguished from the neuroprostheses that make them possible. In itself, a neuroprosthesis is an artificial device that is integrated into the neural circuitry of a human being, typically in order to support or participate in the sensory, cognitive, or motor processes of its human host; however, it can also be used to gather data about its host's biological processes and transmit it to an external computer for medical, archival, or potentially even surveillance purposes.[1] It is possible to view a neuroprosthesis from the perspective of its existence as a self-contained technological device with its own internal structures and dynamics, independently of the way in which it acts on the organism of its human host. When understood as such, the design of neuroprostheses draws heavily on fields such as computer architecture, electronics engineering, and robotics and is in many ways comparable to the design of other complex, specialized computerized devices such as smartphones, communications satellites, or self-driving vehicles. Numerous excellent texts already address the engineering of neuroprostheses understood as this sort of information system that receives input, processes it, and generates output, and this topic is not the focus of the present volume.

[1] See Lebedev, "Brain-Machine Interfaces: An Overview" (2014); Gladden, "Enterprise Architecture for Neurocybernetically Augmented Organizational Systems" (2016); Lorence et al., "Transaction-Neutral Implanted Data Collection Interface as EMR Driver: A Model for Emerging Distributed Medical Technologies" (2009); Bonaci et al., "App Stores for the Brain" (2015), p. 35; Luber et al., "Non-invasive brain stimulation in the detection of deception: Scientific challenges and ethical consequences" (2009); and Gladden, *The Handbook of Information Security for Advanced Neuroprosthetics* (2015).

Similarly, in addition to constituting a computerized system in itself, a neuroprosthesis also serves as a constituent element of the larger biological-electronic system that it creates with the organism of its human host, insofar as the neuroprosthesis and its host's neural circuitry become integrated to form a new hybrid entity, or host-device system. The engineering of such 'cyborgs' and the brain-machine interfaces that constitute their distinguishing characteristic draws largely on fields such as biomedical engineering and neurocybernetics; it is also not the primary focus of this volume.[2] Rather, the subject that will be investigated in this text is the intentional creation of higher-order supersystems that allow multiple neuroprosthetically augmented human beings to interact with one another and with external information systems in order to accomplish some shared task. In essence, this can be understood as the work of designing and managing neuroprosthetically enhanced *organizations*.[3]

Unlike the design of neuroprosthetic devices or host-device systems, the design of neuroprosthetically enhanced organizations is not primarily a question of computer architecture, electronics engineering, biomedical engineering, or neurocybernetics; instead, it is largely a matter of organizational design, organizational architecture, enterprise architecture, and management cybernetics. It is about creating decision-making structures, processes of interaction, and technological systems that allow neuroprosthetically augmented individuals to collaborate in a manner that generates some strategic, operational, or tactical value for their organization, that is efficient and effective, and which satisfies relevant financial, legal, and ethical requirements.

[2] The growing number of ways in which even ordinary human beings are undergoing processes of 'cyborgization' to become functionally integrated with technological systems – and the broader forces of technologization and posthumanization of which the creation of cyborgs is an example – is discussed from various perspectives in, e.g., Haraway, *Simians, Cyborgs, and Women: The Reinvention of Nature* (1991); Tomas, "Feedback and Cybernetics: Reimaging the Body in the Age of the Cyborg" (1995); Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (1999); Anderson "Augmentation, symbiosis, transcendence: technology and the future(s) of human identity" (2003); Clark, *Natural-born cyborgs: Minds, Technologies, and the Future of Human Intelligence* (2004); Fleischmann, "Sociotechnical Interaction and Cyborg–Cyborg Interaction: Transforming the Scale and Convergence of HCI" (2009); and Gladden, *Sapient Circuits and Digitalized Flesh: The Organization as Locus of Technological Posthumanization* (2016).

[3] Lune defines an organization as "a group with some kind of name, purpose, and a defined membership" that possesses "a clear boundary between its inside and its outside" and which can take the form of either a formal organization with clearly defined roles and rules, an informal organization with no explicitly defined structures and processes, or a semi-formal organization that possesses nominal roles and guidelines that in practice are not always observed. See Lune, *Understanding Organizations* (2010), p. 2. Meanwhile, Daft et al. define organizations as "(1) social entities that (2) are goal-directed, (3) are designed as deliberately structured and coordinated activity systems, and (4) are linked to the external environment." See Daft et al., *Organization Theory and Design* (2010), p. 10.

While such neuroprosthetically enhanced organizations can correctly be understood as 'systems' in themselves, for the sake of clarity we will generally use the term 'neuroprosthetic device' to refer to a neuroprosthesis, 'host-device *system*' to refer to a single neuroprosthetically augmented human being, and 'neuroprosthetic *supersystem*' to refer to an organization comprising multiple neuroprosthetically augmented human beings.

The Organization of This Text

This book is divided into two parts. The three chapters of Part I provide an introduction to key building-blocks of neuroprosthetic supersystems by investigating the nature of neuroprosthetic devices and host-device systems and exploring the unique manner in which neuroprosthetically augmented individuals exist in and interact with their digital-physical environments. The four chapters of Part II then consider the reasons why organizations would seek to deploy neuroprosthetic supersystems, ways in which the discipline of enterprise architecture can be employed to manage such supersystems' implementation, the ways in which neuroprosthetic augmentation will impact an organization's use of enterprise architecture, and key principles for the development of effective architectures for neuroprosthetically augmented organizations. Below we describe each of these chapters in more detail.

Part I: Elements of Neuroprosthetic Supersystems

Chapter 1, "An Ontology of the Neuroprosthesis as Computing Device," formulates an ontology that can be employed to describe the fundamental characteristics of a neuroprosthesis in its role as a *computing device*. The ontology draws on existing neuroprosthetic device typologies and ontologies developed for other kinds of devices such as mobile devices and robotic systems. It describes four key aspects that shape the functioning of a neuroprosthesis as computing device: (1) the device's external context (including the human agents who participate in its development and use, factors impacting its availability, and its relationship to the body of its human host); (2) physical components of the neuroprosthesis (including the device's basic morphology, input and output mechanisms, and computational substrate); (3) processes utilized by the device (including computational processes and input and output modalities); and (4) the types of information generated or handled by the device (which may include data regarding the device's status and environment, data regarding the cognitive and biological processes of the device's human host, and procedural and declarative knowledge). The use of such an ontology allows the functionality of a neuroprosthesis as a computing device to be more easily analyzed or designed and facilitates interoperability between neuroprostheses, their human hosts and users, and external computer systems.

In Chapter 2, "Integrating Neuroprostheses into Human Sensory, Cognitive, and Motor Processes," a different sort of ontology is developed that envisions, captures, and describes the full range of ways in which a neuroprosthesis may participate in the sensory, cognitive, and motor processes of its human host. By considering anticipated future developments in neuroprosthetics and adopting a generic biocybernetic approach, this ontology is able to account for therapeutic neuroprostheses already in use as well as future types of neuroprostheses that are expected to be deployed for purposes of human enhancement.

The ontology encompasses three areas. First, a neuroprosthesis may participate in its host's processes of *sensation* by (a) detecting stimuli such as photons, sound waves, or chemicals; (b) fabricating sense data, as in the case of virtual reality systems; (c) storing sense data; (d) transmitting sense data within a neural pathway; (e) enabling its host to experience sense data through a sensory modality such as vision, hearing, taste, smell, touch, balance, heat, or pain; or (f) creating mappings of sensory routes – e.g., in order to allow sensory substitution. Second, a neuroprosthesis may participate in processes of *cognition* by (a) creating a basic interface between the device and the host's conscious awareness or affecting the host's (b) perception, (c) creativity, (d) memory and identity, or (e) reasoning and decision-making. Third, a neuroprosthesis may participate in processes of *motion* by (a) detecting motor instructions generated by its host's brain; (b) fabricating motor instructions, as in the case of a medical device controlled by software algorithms rather than its host's volitions; (c) storing motor instructions; (d) transmitting motor instructions as within a neural pathway; (e) effectuating physical action within effectors such as natural biological muscles and glands, synthetic muscles, robotic actuators, video screens, audio speakers, or wireless transmitters; (f) allowing the expression of volitions through motor modalities such as language, paralanguage, and locomotion; or (g) creating mappings of motor routes. The use of this type of ontology allows easier, more systematic, and more robust analysis of the biocybernetic role of a neuroprosthesis within its host-device system.

Yet another kind of ontology is developed in Chapter 3, "An Ontology of Neuroprostheses as Instruments of Cyborgization: Portals to the Experience of Posthumanized Digital-Physical Worlds." The incorporation of a neuroprosthetic device into one's being at the physical, cognitive, and social levels constitutes a form of 'cyborgization' that imposes new constraints on one's existence while simultaneously opening a path to new forms of experience. This chapter explores the boundaries of this qualitatively novel form of being by formulating an ontology of the neuroprosthesis as an instrument that shapes the way in which its human host experiences and acts within emerging posthumanized digital-physical ecosystems.

This ontology addresses four main roles that a neuroprosthetic device may play in this context. First, a neuroprosthesis may serve as a means of human augmentation by altering the cognitive and physical capacities possessed by its host. Second, it may manipulate the contents of information produced or utilized by its human host. Third, a neuroprosthesis may shape the manner in which its host inhabits a digital-physical body and external environment. And finally, a neuroprosthesis may regulate the autonomous agency possessed and experienced by its host. The use of this type of conceptual framework can allow researchers to better understand the psychological, social, and ethical ramifications of such technologies and can enable the architects of neuroprosthetic systems and the digital-physical ecosystems within which their human hosts operate to formulate principles of design and management that minimize the dangers and maximize benefits for the neuroprosthetically augmented inhabitants of such environments.

Part II: Enterprise Architecture for Neuroprosthetic Supersystems

Chapter 4, "The Organizational Deployment of Posthumanizing Neuroprostheses," examines the types of organizations that are already working to intentionally deploy neuroprosthetic technologies for human enhancement among their workforce (or are expected to do so), factors that can motivate their adoption of such technologies, and the organizational roles that such neurotechnologies may play.

The current state of therapeutic neuroprosthetic device use is presented, along with an overview of posthumanizing neuroprostheses and the types of enhanced capacities that they offer human workers that may be relevant to organizations. A range of factors incentivizing or discouraging the organizational deployment of posthumanizing neuroprostheses is identified and discussed. The organizational roles of therapeutic and posthumanizing neuroprostheses are then analyzed. On the one hand, many organizations already unknowingly incorporate workers possessing therapeutic neuroprostheses. Meanwhile, two key paths for the organizational deployment of posthumanizing neuroprostheses are highlighted. First is the 'transitional augmentation' of human workers as a stopgap measure on the path to eventual full automation of business processes through the use of artificial intelligence. The second path involves retaining human workers in particular positions because exogenous factors (such as legal, ethical, or marketing requirements) mandate that human agents fill those roles, while augmenting the workers so that they can perform more competitively.

It is noted that military organizations play a key role among organizations likely to be early adopters of posthumanizing neuroprostheses. Known and hypothesized military programs for neuroprosthetic enhancement are discussed, along with characteristics of military organizations that remove obstacles that render the deployment of neuroprostheses impractical for most organizations. Other types of organizations are highlighted that share some traits as potential early adopters. Finally, enterprise architecture (EA) is discussed as a preferred management tool for many organizations that are likely to be early adopters. While EA does not directly address the serious ethical and legal questions raised by posthumanizing neuroprosthetics, it can facilitate the functional aspects of integrating neuroprosthetically augmented workers into an organization's personnel structures, business processes, and IT systems.

The potential uses of enterprise architecture as a tool for managing the organizational deployment of neuroprostheses is explored further in Chapter 5, "An Introduction to Enterprise Architecture in the Context of Technological Posthumanization." Enterprise architecture seeks to generate alignment between an organization's electronic information systems, human resources, business processes, workplace culture, mission and strategy, and external ecosystem in order to increase the organization's ability to manage complexity, resolve internal conflicts, and adapt proactively to environmental change. In this chapter, an introduction to the definition, history, organizational role, objectives, benefits, mechanics, and popular implementations of enterprise architecture is presented. The historical shift from IT-centric to business-centric definitions of EA is reviewed, along with the difference between 'hard' and 'soft' approaches to EA. The unique organizational role of EA is highlighted by comparing it with other management disciplines and practices.

The creation of alignment is then explored as the core mechanism by which EA achieves advantageous effects. Different kinds of alignment are defined, the history of EA as a generator of alignment is investigated, and EA's relative effectiveness at creating different types of alignment is candidly assessed. Attention is given to the key dynamic by which alignment yields deeper integration of an organization's structures, processes, and systems, which in turn grants the organization greater agility – which itself enhances the organization's ability to implement rapid and strategically directed change. The types of tasks undertaken by enterprise architects are discussed, and a number of popular enterprise architecture frameworks are highlighted. A generic EA framework is then presented as a means of discussing elements such as architecture domains, building blocks, views, and landscapes that form the core of many EA frameworks. The role of modelling languages in documenting EA plans is also addressed.

In light of enterprise architecture's strengths as a tool for managing the deployment of innovative forms of IT, it is suggested that by adopting EA initiatives of the sort described here, organizations may better position themselves to address the new social, economic, and operational realities presented by emerging posthumanizing technologies such as those relating to social robotics, nanorobotics, artificial life, genetic engineering, neuroprosthetic augmentation, and virtual reality.

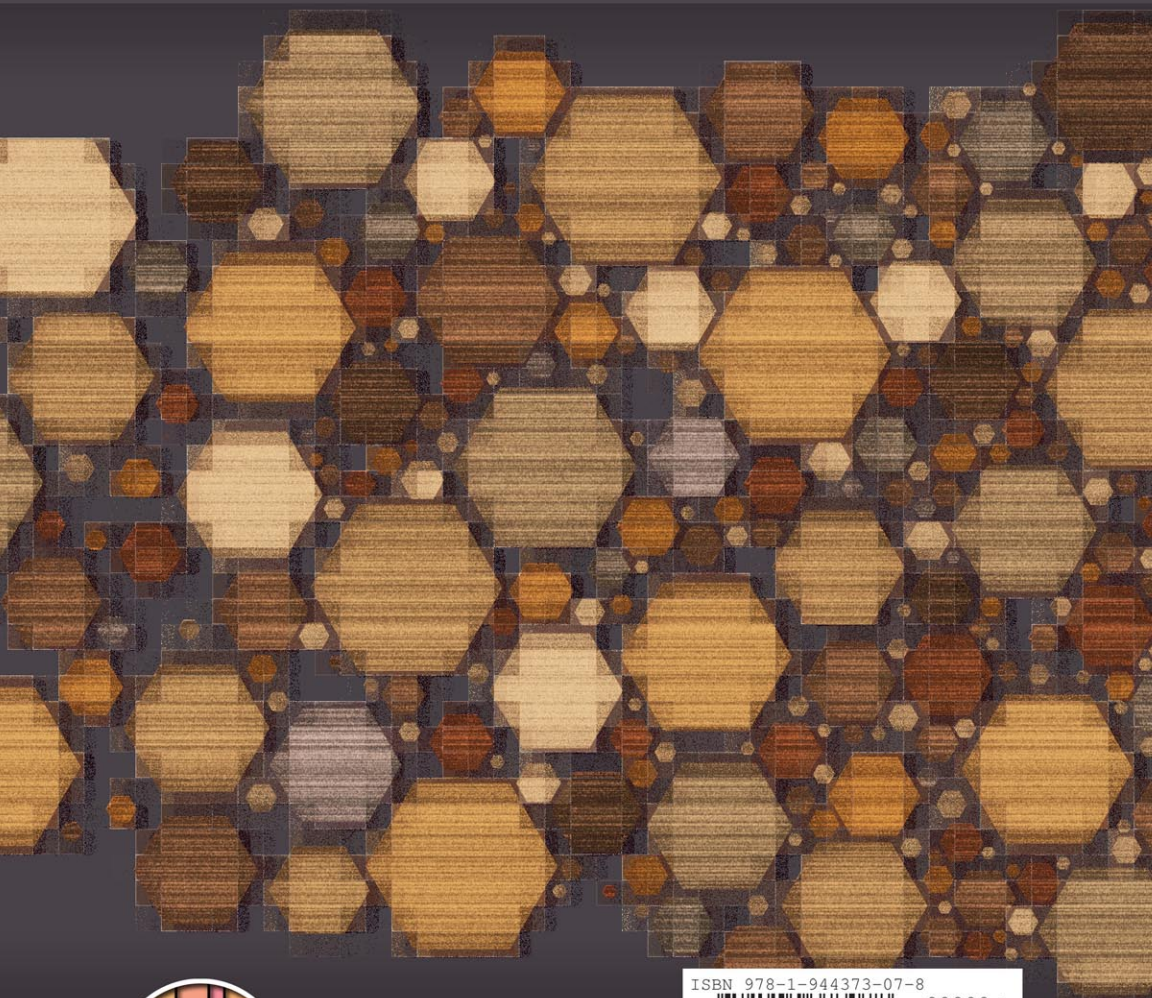
Chapter 6, "The Deepening Fusion of Human Personnel and Electronic Information Systems," explores in more depth the implications of neuroprosthetic augmentation for enterprise architecture. When designing target architectures for organizations, EA has historically relied on a set of assumptions regarding the physical, cognitive, and social capacities of the human beings serving as organizational members. In this chapter we explore the fact that for those organizations that intentionally deploy posthumanizing neuroprosthetic technologies among their personnel, such traditional assumptions no longer hold true: the use of advanced neuroprostheses intensifies the ongoing structural, systemic, and procedural fusion of human personnel and electronic information systems in a way that provides workers with new capacities and limitations and transforms the roles available to them.

Such use of neuroprostheses has the potential to affect an organization's workers in three main areas. First, the use of neuroprostheses may affect workers' physical form, as reflected in the physical components of their bodies, the role of design in their physical form, their length of tenure as workers, the developmental cycles that they experience, their spatial extension and locality, the permanence of their physical substrates, and the nature of their personal identity. Second, neuroprostheses may affect the information processing and cognition of neurocybernetically augmented workers, as manifested in their degree of sapience, autonomy, and volitionality; their forms of knowledge acquisition; their locus of information processing and data storage; their emotionality and cognitive biases; and their fidelity of data storage, predictability of behavior, and information security vulnerabilities. Third, the deployment of neuroprostheses can affect workers' social engagement, as reflected in their degree of sociality; relationship to organizational culture; economic relationship with their employers; and rights, responsibilities, and legal status.

While ethical, legal, economic, and functional factors will prevent most organizations from deploying advanced neuroprostheses among their personnel for the foreseeable future, those select organizations that are already working to develop such technologies and implement them among their personnel will be forced to adapt their enterprise architectures to accommodate the new realities of human-computer integration brought about by posthumanizing neuroprosthetic technologies described in this chapter.

Finally, Chapter 7, "From Virtual Teams to Hive Minds," develops a model based on network topology that can be used to analyze or engineer the structures and dynamics of an organization in which neuroprosthetic technologies are employed to enhance the abilities of human personnel. It is argued that the expanded sensory, cognitive, and motor capacities provided by posthumanizing neuroprostheses may enable human beings possessing such technologies to collaborate using novel types of organizational structures that differ from the traditional structures that are possible for unaugmented human beings. The concept of network topology is then presented as a concrete approach to analyzing or engineering such neuroprosthetic supersystems. A number of common network topologies such as chain, linear bus, tree, ring, hub-and-spoke, partial mesh, and fully connected mesh topologies are discussed and their relative advantages and disadvantages noted.

Drawing on the notion of different architectural 'views' employed in enterprise architecture, we formulate a topological model that incorporates five views that are relevant for neuroprosthetic supersystems: the (1) physical and (2) logical topologies of the neuroprosthetic devices themselves; (3) the natural topology of social relations of the devices' human hosts; (4) the topology of the virtual environments, if any, created and accessed by means of the neuroprostheses; and (5) the topology of the brain-to-brain communication, if any, facilitated by the devices. Potential uses of the model are illustrated by applying it to four hypothetical types of neuroprosthetic supersystems: (1) an emergency medical alert system incorporating body sensor networks (BSNs); (2) an array of centrally hosted virtual worlds; (3) a 'hive mind' administered by a central hub; and (4) a distributed hive mind lacking a central hub. It is our hope that models such as the one formulated here will prove useful not only for engineering neuroprosthetic supersystems to meet functional requirements but also for analyzing the legal, ethical, and social aspects of potential or existing supersystems – to help ensure that the organizational deployment of neuroprosthetic technologies does not undermine the wellbeing of such devices' human users or of societies as a whole.



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