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Chapter Seven in Gladden, Matthew E., Neuroprosthetic Supersystems Architecture, pp. 253-71. Indianapolis: Synthypnion Academic, 2017.
ISBN 978-1-944373-07-8 (print edition) and 978-1-944373-08-5 (ebook).

Chapter Seven

From Virtual Teams to Hive Minds:
Developing Effective Network Topologies for Neuroprosthetically Augmented Organizations

Abstract. This text 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. We begin by defining *neuroprosthetic supersystems* as organizations whose members include multiple neuroprosthetically augmented human beings. 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 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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Introduction

The power and sophistication of neuroprosthetic technologies are rapidly increasing. While a growing number of organizations are incorporating advanced technologies relating to social robotics, artificial intelligence, and virtual reality into their business operations, the notion that organizations would implant neuroprosthetic devices in the brains of their workers in order to enhance productivity might appear to be one which – for the moment – exists primarily within the domain of science fiction and futurology. And yet a small number of specialized organizations are already actively seeking to develop advanced neuroprosthetic technologies and deploy them among their personnel, not simply for therapeutic medical purposes but in order to support and enhance their workers' job performance. Chief among these organizations are military agencies and departments who see in advanced neuroprostheses a means of enhancing the health, safety, and effectiveness of soldiers who must operate in highly dangerous circumstances and upon whose work depends the security of entire nations.[1] Moreover, as new non-invasive neuroprosthetic technologies are developed that do not require dangerous and expensive implant surgery, it is expected that the organizational deployment of 'posthumanizing' neuroprostheses will eventually become feasible and desirable for a wider range of organizations such as businesses.[2]

By their very nature, neuroprosthetic devices create new relationships of communication and control involving their human hosts, the designers and producers of such devices, the medical and IT personnel who maintain them, and the devices themselves. When such devices are purposefully introduced into an organization and deployed among its personnel, they alter in subtle or dramatic ways the manner in which employees interact with one another

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[1] Regarding efforts by DARPA (the US military research agency) and other institutions to develop neurotechnologies for increasing soldiers' alertness and reducing their need for sleep, see, e.g., Falconer, "Defense Research Agency Seeks to Create Supersoldiers" (2003); Moreno, "DARPA On Your Mind" (2004); Clancy, "At Military's Behest, Darpa Uses Neuroscience to Harness Brain Power" (2006); and Wolf-Meyer, "Fantasies of extremes: Sports, war and the science of sleep" (2009). Potential military applications of neurotechnologies for human enhancement are also discussed in Schermer, "The Mind and the Machine. On the Conceptual and Moral Implications of Brain-Machine Interaction" (2009); Brunner & Schalk, "Brain-Computer Interaction" (2009); Coker, "Biotechnology and War: The New Challenge" (2004); Graham, "Imagining Urban Warfare: Urbanization and U.S. Military Technoscience" (2008), p. 36; Krishnan, "Enhanced Warfighters as Private Military Contractors" (2015); and Kourany, "Human Enhancement: Making the Debate More Productive" (2013), pp. 992-93.

[2] At present, for example, cochlear implant surgery can cost between $40,000-$100,000 per person, while implantation surgery for deep brain stimulation (DBS) devices can cost between $35,000-$100,000 per recipient. See "Cochlear Implant Quick Facts" and Okun, "Parkinson's Disease: Guide to Deep Brain Stimulation Therapy" (2014).

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and carry out their roles. This raises the question of how such an organization's formal array of personnel structures, processes, and systems – that is, its organizational architecture[3] – will need to be altered in order to adapt to the presence and activity of neuroprosthetically augmented personnel. That is the question to be investigated in this text, using the lens of *network topology*.

We begin by defining neuroprosthetic supersystems as organizations whose members include multiple neuroprosthetically augmented human beings. The concept of network topology is then presented as a valuable approach to analyzing or engineering such supersystems. A number of common network topologies are discussed, and their relative advantages and disadvantages noted. Building on enterprise architecture's notion of architectural 'views,' we next formulate a topological model that incorporates five views that are relevant for neuroprosthetic supersystems. Finally, potential uses of the model are illustrated by applying it to four types of neuroprosthetic supersystems that could hypothetically be established through an organization's deployment of neuroprosthetic technologies. While the model formulated in this text can facilitate the design of neuroprosthetic supersystems that meet an organization's operational requirements, it also provides a tool for analyzing the legal, ethical, and social aspects of such supersystems – which can help ensure that any organizational deployment of neuroprosthetic technologies is performed in an appropriate manner that not only safeguards the rights and wellbeing of such devices' human hosts but also advances the organization's larger mission and the welfare of society as a whole.

Defining Neuroprosthetic Supersystems

A neuroprosthesis can be defined as *an artificial device that is integrated into the neural circuitry of a human being*.[4] Such devices typically support or participate in the sensory, cognitive, or motor processes of their human host;[5] however, they can also be employed for such ends as gathering real-time data about the host's biological processes and transmitting it to an external computer for medical, archival, or potentially even surveillance purposes.[6] In

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[3] Within the 'congruence model' of organizational architecture conceptualized by Nadler and Tushman, structures, processes, and systems constitute the three main elements of an organization that are taken into account. See Nadler & Tushman, *Competing by Design: The Power of Organizational Architecture* (1997), p. 47.

[4] See Lebedev, "Brain-Machine Interfaces: An Overview" (2014), and Gladden, "Enterprise Architecture for Neurocybernetically Augmented Organizational Systems" (2016).

[5] See Lebedev (2014).

[6] See, e.g., Lorence et al., "Transaction-Neutral Implanted Data Collection Interface as EMR Driver: A Model for Emerging Distributed Medical Technologies" (2009); Bonaci et al., "App

principle, neuroprostheses may be either 'invasive' (i.e., surgically implanted in the brain of a human host) or 'non-invasive' (e.g., consisting of an external device worn by a human host); however, significant challenges exist with developing non-invasive technologies that become truly integrated into the neural circuitry of a human being.[7] Thus, according to the definition used in this text, contemporary neuroprostheses can typically be identified with invasive 'neural implants.'

At present, neuroprosthetic devices are used primarily for therapeutic purposes, as a means of restoring some capacity that is absent as a result of injury or illness: for example, cochlear implants, auditory brainstem implants, and retinal prostheses are used to restore sensory functionality to those who have lost the ability to hear or see; robotic prosthetic limbs are used to replace natural biological limbs that have been amputated; robotic exoskeletons and thought-controlled wheelchairs grant a degree of mobility to the paralyzed; and experimental neural bridges are being developed to restore memory function in individuals who are unable to access their long-term memories due to hippocampal damage.[8] However, efforts are also underway to develop and deploy 'posthumanizing' neuroprostheses[9] whose aim is not to restore some capacity that is found in typical human beings but to grant their human

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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).

[7] See Gasson, "Human ICT Implants: From Restorative Application to Human Enhancement" (2012), p. 14, and Panoulas et al., "Brain-Computer Interface (BCI): Types, Processing Perspectives and Applications" (2010).

[8] See, e.g., Ochsner et al., "Human, non-human, and beyond: cochlear implants in socio-technological environments" (2015); Cervera-Paz et al., "Auditory Brainstem Implants: Past, Present and Future Prospects" (2007); Weiland et al., "Retinal Prosthesis" (2005); Viola & Patrinos, "A Neuroprosthesis for Restoring Sight" (2007); Gasson et al., "Human ICT Implants: From Invasive to Pervasive" (2012); Soussou & Berger, "Cognitive and Emotional Neuroprostheses" (2008); and Gladden, "Neural Implants as Gateways to Digital-Physical Ecosystems and Posthuman Socioeconomic Interaction" (2016).

[9] 'Posthumanizing' technologies can be understood as those that bring about an ecosystem in which entities other than natural biological human beings exist as intelligent agents and social actors that create meaning in the world. Technologies relating to artificial intelligence, artificial life, virtual reality, genetic engineering, and neuroprosthetic augmentation are a catalyst for processes of posthumanization; however, non-technological forces of posthumanization also exist. For more details, see Ferrando, "Posthumanism, Transhumanism, Antihumanism, Metahumanism, and New Materialisms: Differences and Relations" (2013); Herbrechter, *Posthumanism: A Critical Analysis* (2013); Miah, "A Critical History of Posthumanism" (2008); Birnbacher, "Posthumanity, Transhumanism and Human Nature" (2008); and Gladden, *Sapient Circuits and Digitalized Flesh: The Organization as Locus of Technological Posthumanization* (2016).

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hosts sensory, cognitive, and motor capacities that far exceed those that are possible for natural biological human beings.[10]

A neuroprosthetic device can, in itself, be understood as a type of 'system.' The human host of a neural implant is also a type of system, as is the hybrid biological-electronic entity that is created when a neuroprosthetic device becomes integrated into the neural circuitry of its human host. And finally, a group of human beings who possess neuroprosthetic devices can collectively form a system. Use of the word 'system' when discussing such technologies and their implementation can thus be ambiguous. For purposes of clarity, within this text we will use the term 'neuroprosthetic device' to refer to a neuroprosthesis, 'host-device system' to refer to a neuroprosthetically augmented human being, and 'neuroprosthetic supersystem' to refer to a collection of neuroprosthetically augmented human beings. The creation and maintenance of effective neuroprosthetic devices and host-device systems involves fields such as computer science, biology, biomedical engineering, neurosurgery, and bioethics. The creation and maintenance of effective neuroprosthetic supersystems, on the other hand, relies just as strongly on such disciplines as network design, enterprise architecture, organizational design, and management cybernetics. This text explores one aspect of the design and management of neuroprosthetic supersystems by formulating a topological model that can be used to analyze the structure and behavior of neuroprosthetic supersystems and to design architectures for such supersystems that optimize desired characteristics from functional, financial, legal, ethical, and other perspectives.

The Organization of Neuroprosthetic Supersystems as Multi-Agent Systems

An organization such as a business or government agency can be understood as a specialized type of multi-agent system composed of autonomous intelligent agents. Historically, such agents have primarily been human beings, although some organizations (such as ranches or military units) have long incorporated non-human agents such as trained dogs or horses in certain roles. Today, organizations increasingly incorporate social robots, chatbots, and other artificial agents that perform specialized functions: while such artificial agents may not appear in an organization's formal (human) personnel structure, they must be taken into account by any cybernetic analysis of the organization's internal processes of communication and control.

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[10] See, e.g., McGee, "Bioelectronics and Implanted Devices" (2008); Warwick & Gasson, "Implantable Computing" (2008); Gasson (2012); Gladden, "Neural Implants as Gateways" (2016); and Gladden, "Enterprise Architecture for Neurocybernetically Augmented Organizational Systems" (2016).

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There are many different ways in which an organization's agents might be grouped and their interactions arranged in an effort to maximize the organization's efficiency and productivity. Horling and Lesser note that the range of potential organizational forms available to contemporary organizations includes hierarchies (which can be either simple, uniform, or multi-divisional), holarchies (or 'holonic organizations'), coalitions, teams, congregations, societies, federations (or 'federated systems'), matrix organizations, compound organizations, and sparsely connected graph structures (which may either possess statically defined elements or be an 'adhocracy').[11] Such structures have been developed over time to suit the unique characteristics of the key members that constitute contemporary organizations – i.e., natural biological human beings. However, for organizations that deploy posthumanizing neuroprosthetic technologies among their personnel, new types of organizational structures are expected to become feasible – or perhaps even necessary. For example, an organization that is composed of neuroprosthetically augmented human members may be able to link them by means of a decentralized network that enables the direct sharing of thoughts and emotions between members' minds, allowing information to be disseminated instantaneously and decisions to be made in a collective manner that is not possible for conventional human organizations.[12] However, the fact that such new types of personnel structures may become technologically possible does not necessarily mean that they are desirable or appropriate from an operational, financial, legal, or ethical perspective. The planning and evaluation of organizational structures for neuroprosthetic supersystems can be supported by the use of models that highlight critical aspects of such structures.

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[11] See Horling & Lesser, "A Survey of Multi-Agent Organizational Paradigms" (2004), and Gladden, *Posthuman Management: Creating Effective Organizations in an Age of Social Robotics, Ubiquitous AI, Human Augmentation, and Virtual Worlds* (2016), p. 122.

[12] Regarding the potential creation of hive minds and neuroprosthetically facilitated collective intelligences, see, e.g., McIntosh, "The Transhuman Security Dilemma" (2010); Roden, *Posthuman Life: Philosophy at the Edge of the Human* (2014), p. 39; and Gladden, "Utopias and Dystopias as Cybernetic Information Systems: Envisioning the Posthuman Neuropolity" (2015). For a classification of different kinds of potential hive minds, see Chapter 2, "Hive Mind," in Kelly, *Out of Control: The New Biology of Machines, Social Systems and the Economic World* (1994); Kelly, "A Taxonomy of Minds" (2007); Kelly, "The Landscape of Possible Intelligences" (2008); Yonck, "Toward a standard metric of machine intelligence" (2012); and Yampolskiy, "The Universe of Minds" (2014). For critical perspectives on hive minds, see, e.g., Maguire & McGee, "Implantable brain chips? Time for debate" (1999); Bendle, "Teleportation, cyborgs and the posthuman ideology" (2002); and Heylighen, "The Global Brain as a New Utopia" (2002).

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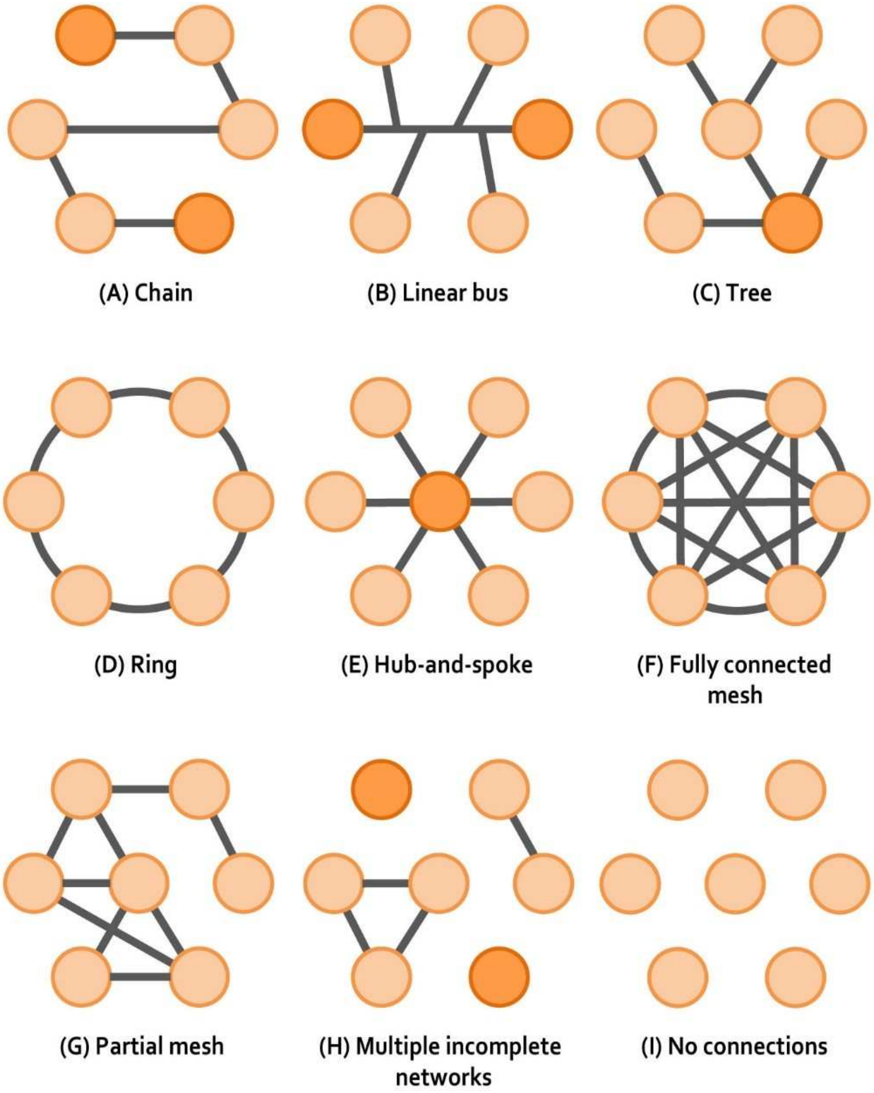

Fig 1: An overview of basic types of network topologies, including the (A) chain (or line), (B) linear bus, (C) tree, (D) ring, (E) hub-and-spoke (or star), (F) fully connected mesh, and (G) partial mesh topologies, along with depictions of (H) multiple incomplete networks that fail to connect all of the nodes and (I) a complete lack of connections between nodes. In some topologies, one or more nodes are highlighted to indicate their special roles, including the endpoints in the (A) chain and (B) linear bus topologies, the root node in the (C) tree topology, the hub in the (E) hub-and-spoke topology, and those nodes that are excluded from any networks in the case of (H) multiple incomplete networks.

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An Overview of Network Topology

One useful approach to analyzing or engineering neuroprosthetic supersystems within an organization employs the concept of **network topology**. Network topology is often utilized in planning and managing collections of computer hardware such as file servers, local area networks that link desktop computers, or an organization's infrastructure of Wi-Fi routers. However, network topology is also employed in many other contexts, such as analysis of the social relationships that exist within a human population or the design of approval procedures for financial transactions within an organization.[13] For our purposes, the relevant characteristic of network topology is its ability to provide a simplified schematic representation of the complex dynamics of a system's internal behaviors by depicting the system as a set of objects or components (here referred to as 'nodes') that are related to one another through a set of links or 'connections' that allow one node to control, communicate with, or otherwise impact another. Figure 1 presents an overview of several elementary network topologies that are found within a wide range of settings, both within the natural world and in artificial systems.

Each type of network topology possesses its own unique strengths and weaknesses. Different topologies might be selected for use within a network, depending on whether its engineer prioritizes speed, efficiency, ease of maintenance, resilience, security, cost minimization, or other characteristics. We can consider each of these basic network topologies in more detail.

A **chain (or line) topology** links all of the nodes in a series. A message sent from one endpoint node to the other endpoint node must travel through all of the other nodes in order to reach its destination. For a network containing a large number of nodes, the quantity of communications traffic passing through the central nodes and connections can be quite high in comparison to the traffic experienced at the ends of the chain. Severing a connection anywhere along the chain will create at least one pair of nodes that are no longer able to communicate; disabling an interior (non-endpoint) node will have the same effect.

A **linear bus topology** employs a backbone transmission mechanism (or 'bus') that connects two endpoint nodes, with all of the other nodes also connecting directly to the bus. A message that is transmitted into the bus by a given node will be simultaneously received by all other nodes.

A **tree topology** is a hierarchical structure including a single root node with connections that branch like the boughs of a tree. Travelling away from the

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[13] For an overview of network topology in the context of designing and maintaining computer networks, see, e.g., Robertazzi, *Networks and Grids: Technology and Theory* (2007), and Sosinsky, *Networking Bible* (2009). For a discussion of network topology in the context of social networks, see McCulloh et al., *Social Network Analysis with Applications* (2013).

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root node, a given ‘parent’ node may have any number of ‘child’ nodes, but a given child node will have only a single parent. For any two nodes, there will be a single shortest path connecting them; messages sent between the two nodes may need to travel a short or long distance, depending on (for example) whether the nodes lie along the same branch or are the endpoints of different branches that split all the way back at the root node.

A **ring topology** creates a closed circuit linking all of the nodes. In typical implementations of ring networks for computers, the messages sent between nodes only travel in a single direction; in that sort of arrangement, severing a connection anywhere will render at least some of the nodes unable to communicate with one another. In a ring that utilizes bidirectional communication, severing a single connection will increase the distance between some of the nodes and the time needed for messages to travel between them, but it will not leave any of the nodes unable to communicate with others.

A **hub-and-spoke (or star) topology** utilizes as a single node as a hub through which all messages must pass. This model allows for effective centralized control of communications: the hub node may decide which messages are allowed to pass between which nodes. However, the hub also represents a single point of failure: if the hub is disabled, all communication between the remaining hubs is completely severed. A major issue in the design of hub-and-spoke networks is determining exactly where to locate the hub in order to maximize efficiency, security, or other characteristics of the network; Figure 2 depicts such a scenario. Numerous approaches have been developed for using artificial intelligence to optimize the position of hubs within large hub-and-spoke networks.[14]

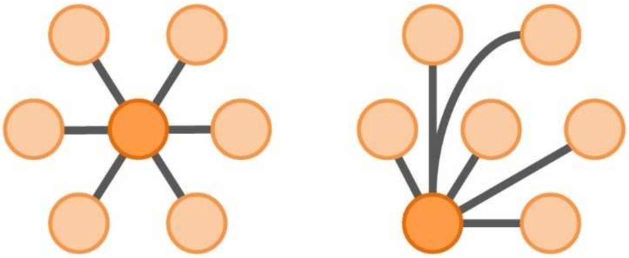

Fig 2: Two different ways in which a hub-and-spoke (or star) network could be constructed to connect the same set of nodes by utilizing different hub placements.

A **fully connected mesh topology** enables direct communication between every pair of nodes in the network. Such a network is highly efficient, insofar

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[14] See, e.g., Alumur & Kara, “Network hub location problems: The state of the art” (2008).

as a message between any two nodes always travels along the shortest possible path. Such a network is also maximally robust and resilient: even if many of a node's connections were to be severed, it would retain the ability to exchange messages with every other node in the network, as long as at least one of its connections remained intact. However such networks require the creation and maintenance of a large and complex infrastructure of connections.

A **partial mesh topology** incorporates a variety of topologies to create a network that includes some subregions that are fully connected meshes but which – as a whole – is not fully connected. Some areas of the network may be rich in connections, while other nodes (such as those that are less important or which generate or receive less communication traffic) may only have direct connections to a limited number of other nodes. Use of such a topology allows a network to enjoy some of the benefits of efficiency and resilience found in a fully connected mesh topology but without the creation of such a complex infrastructure of connections.

It is also possible for nodes to comprise **multiple incomplete networks**; in such an arrangement, at least some of the nodes within a system possess connections with other nodes, but there are also some pairs of nodes that are not able to communicate with one another. Such an arrangement might be purposefully implemented (e.g., in order to maximize security by isolating some nodes from the network), or it might arise unintentionally (e.g., as a result of damage to nodes or connections that severs some of the network's internal communication paths).

It is also possible for there to be a **complete lack of connections** between any nodes in the system. This means that nodes cannot communicate with one another or control one another's activities.

The Roles of Network Topologies in Neuroprosthetic Supersystems

The relationships of an organization's human members cannot typically be fully and accurately represented using just a single network topology. For example, Figure 3 presents an overview of a hypothetical organization that includes seven employees: it illustrates the fact that the network topology of the relationships between the organization's members takes on a very different form depending on whether one analyzes the relationships through the lens of the organization's formal personnel structure, the communication enabled by its email system, or the face-to-face interaction that the employees experience in the workplace.

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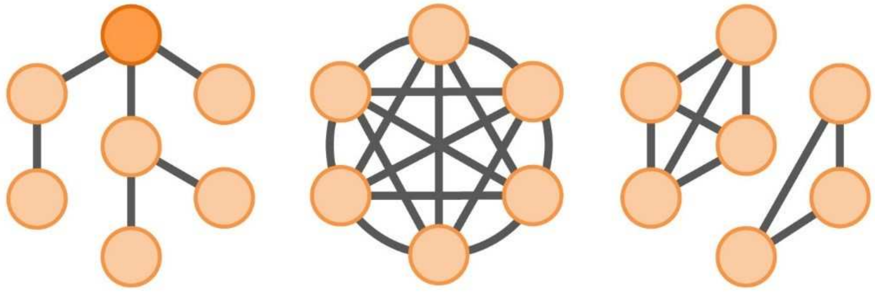

(A) Personnel structure **(B) Email communication** **(C) Face-to-face interaction in facilities**

Fig 3: Three ways in which the network topology of the relationships of an organization’s employees may be represented by using different perspectives. The employees can be viewed according to (A) the official personnel structure governing their decision-making authority and reporting relationships, (B) the fact that any employee may communicate with any other by means of the organization’s email system, or (C) the fact that the employees work in two different buildings in different countries, which divides the employees into two groups of persons that can interact face-to-face among themselves but not with workers in the other facility.

Enterprise Architecture and Organizational Views

The discipline of enterprise architecture (EA) emerged in the 1980s and 1990s as a response to the fact that organizations deploying new computerized information systems were failing to realize expected gains in productivity and efficiency – in large part, because the acquisition of such systems was not guided by the organizations’ larger business strategies and the systems were not being effectively integrated into the organizations’ existing structure and dynamics.[15] Enterprise architecture seeks to facilitate the successful integration of such new information technologies into an organization by generating ‘alignment’ between the organization’s electronic information systems, human resources, business processes, workplace culture, mission and strategy, and external ecosystem, which increases the organization’s ability to manage complexity, resolve internal conflicts, and adapt proactively to environmental change.[16]

Enterprise architecture formalizes different ways of viewing an organization’s network topologies through the concept of ‘viewpoints’ and the preparation of documents known as ‘views.’[17] A number of models exist that define

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[15] See Magoulas et al., “Alignment in Enterprise Architecture” (2012), p. 89, and Hoogervorst, “Enterprise Architecture: Enabling Integration, Agility and Change” (2004), p. 16.

[16] Regarding different types of alignment generated by EA, see Chan & Reich, “IT alignment: what have we learned?” (2007); Magoulas et al. (2012); and Gladden, “Enterprise Architecture for Neurocybernetically Augmented Organizational Systems” (2016).

[17] For a more detailed exposition of the fundamentals of enterprise architecture, see Chapter 5 of this work.

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different views. For example, Kruchten’s ‘4+1’ model was developed primarily to support the practice of software design, although it has been influential within the field of EA more broadly: as a means of analyzing the components and internal relationships of an information system, it defines the *logical view* (which employs the perspective of end-user functionality), *process view* (which focuses on communication, integration, and other system behaviors and dynamics), *development view* (which is prepared from the perspective of the design, implementation, and management of software), and *physical view* (which focuses on the deployment and interconnection of hardware components).[18] Similarly, the Siemens EA Framework described by Rohloff explicitly formulates the three perspectives of *component*, *communication*, and *distribution* views.[19] The generic EA framework that we present in Chapter 5 of this text (and which builds on the approaches of Kruchten and Siemens) incorporates three primary perspectives on architecture domains: the *component*, *interaction*, and *membership* views.[20]

Defining a Model of Relevant Views for Neuroprosthetic Supersystems

It is possible to define at least five topological views that are relevant for analyzing, designing, and maintaining neuroprosthetic supersystems. Two of these relate primarily to the neuroprosthetic devices themselves:

- The **physical neuroprosthetic device topology** reflects the physical connections that exist between the neuroprostheses possessed by different human hosts within the organization. Such physical connections may be hardwired (e.g., utilizing generic Cat 5 Ethernet or fiber optic cables), may be wireless (e.g., utilizing radio-based Wi-Fi or Bluetooth, infrared, or laser transmissions), or may combine wired and wireless components.
- The **logical neuroprosthetic device topology** reflects the ways in which the software or other control processes within the supersystem allow its neuroprostheses to communicate with one another. This may dif-

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[18] See Kruchten, “The 4+1 view model of architecture” (1995), and Part 8.1 of *ArchiMate® 2.1 Specification* (2015).

[19] See Rohloff, “Framework and Reference for Architecture Design” (2008), pp. 5-6.

[20] In our generic EA framework, the component view highlights all of the entities that together constitute the enterprise, including employees, physical facilities, computing devices, vehicles, products, and financial, material, and informational resources, as well as the capacities and internal processes that these entities possess. The interaction view highlights the network topology of the ways in which these entities are connected to one another and the processes (such as those of communication and control) by which they interact. The membership view highlights the boundaries and occupants of those spatiotemporal regions (such as physical buildings, countries, time zones, or virtual environments) within which organizational elements are located or operate and of those functional or conceptual groupings (such as corporate departments or project teams) to which elements belong or to whose authority they are subject. See Chapter 5 of this text for more details.

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fer from the devices' physical topology. For example, consider a situation in which each of a supersystem's neuroprostheses has the physical capacity to transmit radio signals to and receive radio signals from any other neuroprosthesis in the supersystem, however each device's built-in security software only processes an incoming message and delivers it to the device's host if the message was sent by a neuroprosthesis belonging to that host's direct supervisor or to a direct subordinate. In this case, the neuroprostheses' physical topology would constitute a fully connected mesh, but the logical topology would take the form of a hierarchical tree topology.

Three other relevant views relate primarily to the devices' human hosts, in their role as embodied and embedded intelligences and social actors:

- The **human hosts' natural social topology** reflects social relations between individual human beings within the organization that are not dependent on neuroprosthetic devices. Such relations may already have existed prior to individuals' neuroprosthetic augmentation or may have been developed after their augmentation but without the facilitation of neuroprostheses; they might continue to exist even if the supersystem's neuroprostheses were disabled.
- The topology of the **neuroprosthetically facilitated virtual environment** reflects the 'inhabitants' of the virtual environments, if any, that are created by means of the neuroprostheses and which provide an opportunity for social interaction among the human hosts who spend time in such an environment – even if they do not, in practice, directly interact with one another within that venue.[21] Such immersive virtual environments might include shared virtual spaces that are created temporarily to facilitate the completion of a team's particular tasks, or they might be persistent and massively multiuser virtual worlds that fill a general organizational role.
- The topology of **neuroprosthetically facilitated brain-to-brain communication** reflects the lines of communication, if any, that are established within the supersystem directly between the brains of human hosts by means of their neuroprostheses.[22] Such communication might

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[21] For a practical overview of virtual teams, see Zofi, *A Manager's Guide to Virtual Teams* (2012), and Settle-Murphy, *Leading Effective Virtual Teams: Overcoming Time and Distance to Achieve Exceptional Results* (2012). Various aspects of virtual organizations are discussed in Fairchild, *Technological Aspects of Virtual Organizations: Enabling the Intelligent Enterprise* (2004); *Virtual Organizations: Systems and Practices*, edited by Camarinha-Matos et al. (2005); and Shekhar, *Managing the Reality of Virtual Organizations* (2016). The broader implications of long-term immersion in virtual reality environments are discussed in Bainbridge, *The Virtual Future* (2011); Heim, *The Metaphysics of Virtual Reality* (1993); and Koltko-Rivera, "The potential societal impact of virtual reality" (2005).

[22] Regarding such possibilities, see, e.g., Rao et al., "A direct brain-to-brain interface in humans" (2014), and Gladden, "Utopias and Dystopias as Cybernetic Information Systems" (2015).

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conceivably take a number of forms, from the simple hands-free composition and sending of text messages by means of participants' thoughts to the full integration of hosts' sensory experiences, memories, and volitions in order to fashion a 'hive mind' possessing a shared will.

Additional types of views are certainly possible and may be critical for particular types of systems and organizational contexts. However, taken together, the five basic views described above provide a robust representation of the network topologies of a neuroprosthetic supersystem that can be useful for such diverse purposes as system design and engineering, system management, information security planning, and ethical analysis.

The Dynamic Nature of Neuroprosthetic Topologies

When analyzing or engineering network topologies for neuroprosthetic supersystems, it should be noted that a network may change its topology periodically or even continually. For example, hosts' access to virtual environments may be added or removed as needed, in order to enforce information security policies[23] or minimize resource consumption. Some networks utilize *ad hoc* and dynamically reconfigurable topologies that can be updated as needed to reflect a network's change in membership, purpose, or operational context. Networks may incorporate artificially intelligent control mechanisms that autonomously detect changing internal or environmental conditions and adapt the network's design (e.g., by relocating the position of a logical hub) according to fixed rules; other networks may possess configurations that were not intentionally designed but which were developed through the use of evolutionary algorithms that optimize desirable performance characteristics.[24]

Applying the Topological Model to Hypothetical Neuroprosthetic Supersystems

In order to illustrate the role of the five basic topological views in describing a neuroprosthetic supersystem, below we use the views to depict the neuroprosthetic supersystems of four very simple hypothetical organizations.

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[23] For example, the InfoSec principle of purposefully structuring access for least functionality and least privilege is discussed in *NIST Special Publication 800-53, Revision 4: Security and Privacy Controls for Federal Information Systems and Organizations* (2013), pp. F-71-F-73, F-179.

[24] Regarding such approaches to networks in various contexts, see, e.g., Gen et al., *Network Models and Optimization: Multiobjective Genetic Algorithm Approach* (2008); *Adaptive Networks: Theory, Models and Applications*, edited by Gross & Sayama (2009); LoBello & Toscano, "An adaptive approach to topology management in large and dense real-time wireless sensor networks" (2009); and *Self-Organizing Networks (SON): Self-Planning, Self-Optimization and Self-Healing for GSM, UMTS, and LTE*, edited by Ramiro & Hamied (2012).

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Scenario 1: An Emergency Medical Alert System

Figure 4 depicts the five basic topological views as applied to a neuroprosthetically enabled medical alert system. Each member of the organization possesses a neuroprosthetic device that monitors its host's biological processes and medical condition by means of a body sensor network (BSN) comprising numerous implanted sensors. If a host should experience a debilitating injury or sudden illness that renders him or her unconscious, that host's neuroprosthesis detects that occurrence and transmits a medical alert and call for help that is communicated simultaneously to all of the other hosts' devices by means of a shared bus. The human hosts all interact periodically with one another through non-neuroprosthetic social channels, and the neuroprosthetic network does not create a shared virtual environment or enable direct brain-to-brain communication.

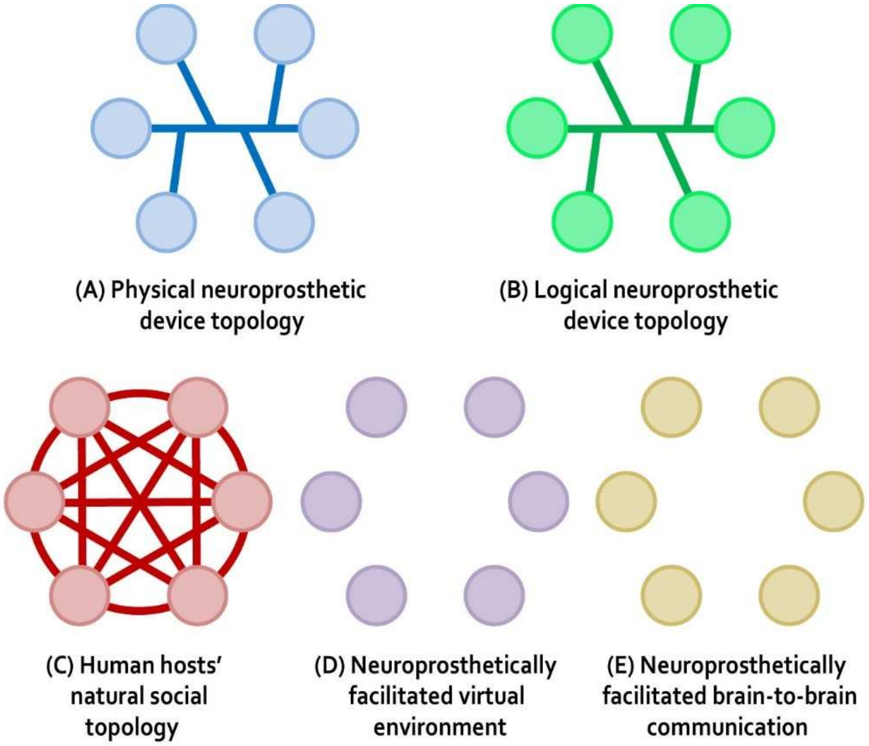

Fig 4: A neuroprosthetic network that provides an emergency medical alert system. The devices themselves are linked through a physical (A) and logical (B) bus; their human hosts all interact periodically with one another through non-neuroprosthetic social channels (C). The neuroprostheses do not create a shared virtual world (D) or provide direct brain-to-brain communication (E).

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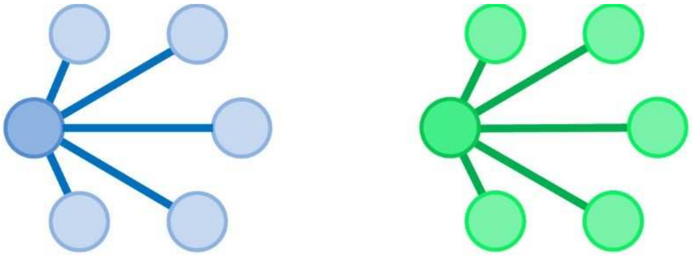
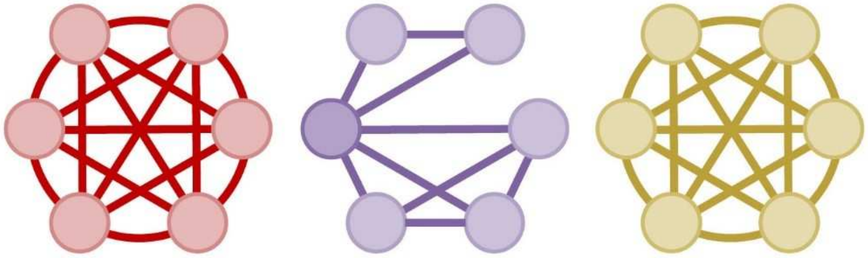
Scenario 2: Centralized Hosting of Multiple Virtual Worlds

Figure 5 depicts the use of neuroprosthetic devices to create a set of virtual worlds that are administered by a single host’s neuroprosthesis. Each of the organization’s human members has access to one of two virtual worlds, depending on his or her organizational role – except for the host of the neuroprosthesis serving as the system’s hub, who has access to both virtual worlds. All of the hosts interact with one another in their shared physical workplace. The neuroprosthetic network also allows each human host to mentally compose and send text messages to any other host, thus enabling a basic form of brain-to-brain communication. Disabling of the hub neuroprosthesis would shut down the virtual environments and brain-to-brain communication.



(A) Physical neuroprosthetic device topology

(B) Logical neuroprosthetic device topology



(C) Human hosts’ natural social topology

(D) Neuroprosthetically facilitated virtual environment

(E) Neuroprosthetically facilitated brain-to-brain communication

Fig 5: A neuroprosthetic network in which a single device serves as the hub of physical (A) and logical (B) hub-and-spoke networks in order to maintain two distinct virtual environments (D) and enable brain-to-brain communication (E) among all hosts – who also interact socially in their shared physical workplace (C).

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Scenario 3: A Hive Mind with a Central Hub

Figure 6 depicts the use of neuroprosthetic devices to fashion a 'hive mind' whose human members share memories, emotions, and desires to create a collective entity with a common will. In this case, one neuroprosthetic device serves as the physical hub for the network, allowing all of the other devices to communicate with one another through it. Some of the network's human hosts interact with one another in their physical workplace, but others are physically isolated and interact only by means of the neuroprosthetic network. The neuroprostheses allow direct brain-to-brain communication between hosts, but do not override or interfere with the hosts' natural biological sensory systems in order to create a shared virtual world.

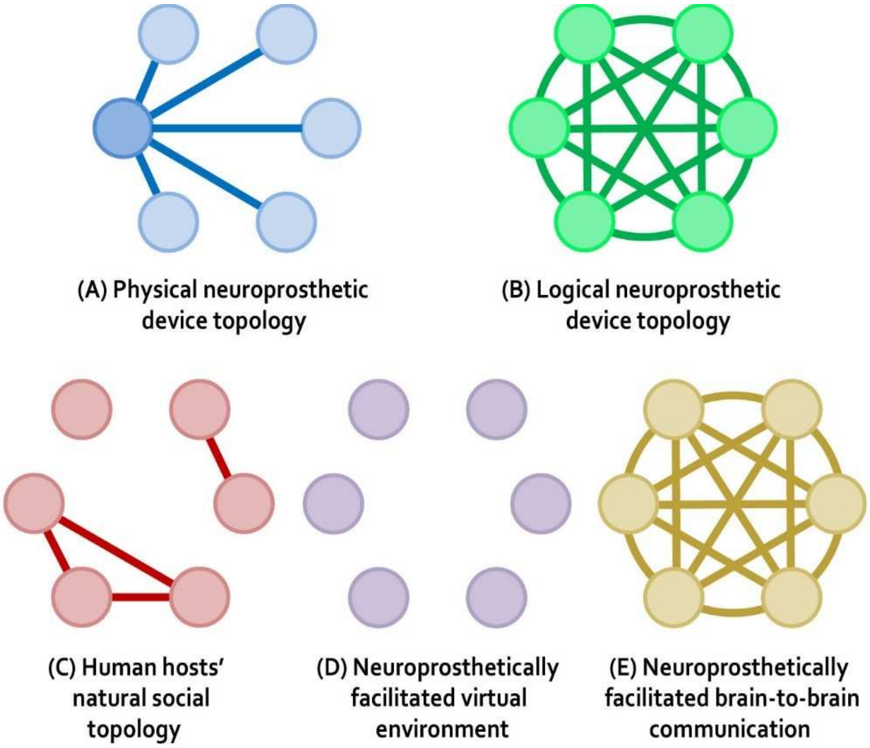

Fig 6: A neuroprosthetic supersystem that links its human members to create a centralized hive mind. One neuroprosthesis serves as the physical hub in a hub-and-spoke topology (A) to create a fully connected logical mesh including all devices (B). The network creates direct brain-to-brain communication (E) but not a shared virtual environment (D) for its human members, only some of whom enjoy social relations in the physical workplace (C).

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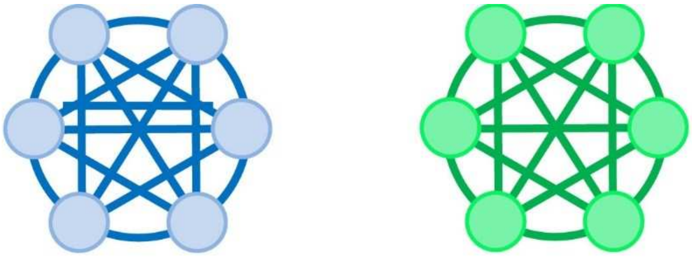
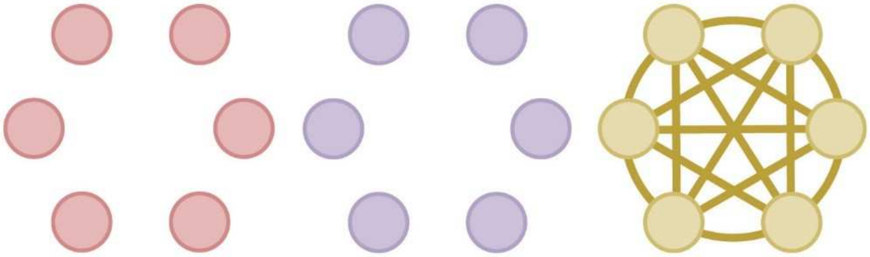
Scenario 4: A Distributed Hive Mind Lacking a Central Hub

Figure 7 depicts the use of neuroprosthetic devices to create a decentralized hive mind that lacks a central physical or logical hub: any new device joining the network establishes direct physical and logical connections with all other devices, and the disabling of a node or severing of individual connections does not imperil the functioning of the network as a whole. The network's human members do not interact socially in the primary physical world and do not have access to a shared virtual environment; however, by means of the neuroprosthetic network they are able to share their internal monologues,[25] imaginings, and volitions to forge collective decisions.



(A) Physical neuroprosthetic device topology

(B) Logical neuroprosthetic device topology



(C) Human hosts' natural social topology

(D) Neuroprosthetically facilitated virtual environment

(E) Neuroprosthetically facilitated brain-to-brain communication

Fig 7: A neuroprosthetically facilitated hive mind whose neuroprostheses all enjoy direct physical (A) and logical (B) connections with one another. The network's human hosts do not interact socially in the primary physical world (C) and do not inhabit a shared virtual environment (D); however, their brains communicate directly in a fully connected mesh (E).

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[25] For an overview of such cognitive processes, see "The Internal Monologue" in Butler, *Rethinking Introspection* (2013), pp. 119-47.

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Conclusion

For most contemporary organizations, the notion of intentionally integrating posthumanizing neuroprosthetic technologies into the workplace has no relevance as a strategic, operational, or tactical possibility. However, for the select group of specialized organizations (such as military departments) that are actively seeking to develop and deploy such technologies among their personnel, complex questions are emerging that relate not only to such devices' biological and technological elements but also to their *organizational* aspects. For example, how can such technologies be most effectively incorporated into an organization's personnel structures, business processes, and information systems? In this text, we have investigated one facet of that question by developing a model based on the concepts of network topology and enterprise architecture's technique of analyzing an organization through the lens of different formalized 'views.' Our model incorporates five views whose uses we have explored by applying the model to four types of neuroprosthetic supersystems that might be established through the deployment of neuroprosthetic technologies. While such a model can be of immediate use for those organizations that are considering the possibility of implementing posthumanizing neuroprosthetic technologies – or that are already actively working to deploy them – it may also be of use to policymakers, social scientists, ethicists, and others who are seeking to understand the implications of organizations' potential exploitation of neuroprosthetic technologies and to establish the parameters for their use, in order to ensure that such technologies are employed in ways that are consistent with the rights of their human users and which benefit rather than harm the organizations deploying them and human society as a whole.

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"From Virtual Teams to Hive Minds: Developing Effective Network Topologies for Neuroprosthetically Augmented Organizations,"
Chapter Seven in Gladden, Matthew E., Neuroprosthetic Supersystems Architecture, pp. 253-71. Indianapolis: Synthypnion Academic, 2017.
ISBN 978-1-944373-07-8 (print edition) and 978-1-944373-08-5 (ebook).