

Matthew E. Gladden

Institute of Computer Science, Polish Academy of Sciences

Neural implants as gateways to digital-physical ecosystems and posthuman socioeconomic interaction

Introduction

For many employees, "work" is no longer something performed while sitting at a computer in an office. Employees in a growing number of industries are expected to carry mobile devices and be available for work-related interactions even when beyond the workplace and outside of normal business hours. In this article it is argued that a future step will increasingly be to move work-related information and communication technology (ICT) inside the human body through the use of neuroprosthetics, to create employees who are always "online" and connected to their workplace's digital ecosystems. At present, neural implants are used primarily to restore abilities lost through injury or illness, however their use for augmentative purposes is expected to grow, resulting in populations of human beings who possess technologically altered capacities for perception, memory, imagination, and the manipulation of physical environments and virtual cyberspace. Such workers may exchange thoughts and share knowledge within posthuman cybernetic networks that are inaccessible to unaugmented human beings.

Scholars note that despite their potential benefits, such neuroprosthetic devices may create numerous problems for their users, including a sense of alienation, the threat of computer viruses and hacking, financial burdens, and legal questions surrounding ownership of intellectual property produced while using such implants. Moreover, different populations of human beings may eventually come to occupy irreconcilable digital ecosystems as some persons embrace neuroprosthetic technology, others feel coerced into augmenting their brains to compete within the economy, others might reject such technology, and still others will simply be unable to afford it.

In this text we propose a model for analysing how particular neuroprosthetic devices will either facilitate human beings' participation in new forms of socioeconomic interaction and digital workplace ecosystems—or undermine their mental and physical health, privacy, autonomy and authenticity. We then show how such a model can be used to create device ontologies and typologies that help us classify and understand different kinds of advanced neuroprosthetic devices according to the impact that they will have on individual human beings.

From Neuroprosthetic Devices to Posthuman Digital-Physical Ecosystems

Existing Integration of the Human Brain with Work-Related Digital-Physical Ecosystems

In recent decades the integration of the human brain with work-related digital ecosystems has grown stronger and increasingly complex. Whereas once employees were expected to use desktop computers during "working hours," for a growing number of employees it is now expected that they be available for work-related interactions at all times through their possession and mastery of mobile (and now, wearable) devices (Shih 2004; Gripsrud 2012). Along this path of ever closer human-technological integration, an emerging frontier is that of moving computing inside the human body through the use of implantable computers (Koops & Leenes 2012; Gasson 2012; McGee 2008).

The Potential of Neuroprosthetic Implants for Human Enhancement

One particular type of implantable computer is a neuroprosthetic device (or neural implant) designed to provide a human being with some sensory, cognitive, or motor capacity (Lebedev 2014). Such neuroprostheses are currently used primarily for therapeutic purposes, to restore abilities that have been lost due to injury or illness. However, researchers have already developed experimental devices designed for purposes of human enhancement that allow an individual to exceed his or her natural biological capacities by, for example, obtaining the ability to perceive ultrasonic waves or store digitized computer files within one's body (Warwick 2014; Gasson 2012; McGee 2008).

Toward Posthuman Digital-Physical Ecosystems

The use of neuroprosthetics for purposes of human enhancement is expected to grow over the coming decades, resulting in a segment of the population whose minds possess unique kinds of sensory perception, memory, imagination, and emotional intelligence and who participate in social relations that are mediated not through the exchange of traditional oral, written, or nonverbal communication but by neurotechnologies that allow the sharing of thoughts and volitions directly with other human minds and with computers (McGee 2008; Warwick 2014; Rao, Stocco, Bryan, Sarma, Youngquist, Wu, & Prat 2014).

Until now, communicating a thought to another mind has required the thought to be expressed physically as a social action that is audible, visible, or tangible in nature, however future neuroprosthetics may facilitate the exchange of ideas directly at the level of thought (Warwick 2014; Rao et al. 2014; Gladden 2015d), thereby allowing the creation of human networks that can be understood as either "supersocial" or "postsocial" in nature. Not only might such posthuman (Ferrando 2013) digital ecosystems be inaccessible to those who lack the appropriate form of neural augmentation, but even their very existence may be invisible to unmodified human beings.

In this text, we will often refer to such ecosystems as "digital" to emphasise the fact that they may utilize an immersive cyberspace or other artificial environment as a virtualized locus for socioeconomic interaction. However, it should be kept in mind

that any such virtual reality is always grounded in and maintained by the computational activity of electronic or biological physical substrates; thus technically, digital ecosystems should always be understood as "digital-physical" ecosystems.

The Need to Analyse Neuroprosthetics from Cybernetic, Phenomenological, and Existentialist Perspectives

As a bidirectional gateway, a neural implant not only aids one's mind to reach out to explore the world and interact with other entities; it may also allow external agents or systems to reach into one's mind to access—and potentially manipulate or disrupt—one's most intimate mental processes (Gasson 2012: 15–16). This makes it essential that manufacturers who produce such devices, policymakers who can encourage or ban their adoption, and users in whom they will be implanted be able to understand the positive and negative impacts of particular neuroprosthetic devices on individual users. This calls for the development of device ontologies and typologies for classifying and understanding neuroprostheses that do not simply focus on the devices' technical characteristics but which also consider a user's lived experience of a neuroprosthetic device and which integrate a cybernetic analysis of "control and communication" (Wiener 1961) with phenomenological and even existentialist perspectives (Gladden 2015d).

Existing Ontologies and Typologies of Neuroprosthetic Devices

Existing typologies for neuroprosthetics are primarily functional. For example, a neuroprosthetic device can be classified based on the nature of its interface with the brain's neural circuitry [sensory, motor, bidirectional sensorimotor, or cognitive (Lebedev 2014)], its purpose [for restoration, diagnosis, identification, or enhancement (Gasson 2012: 25)], or its location [non-invasive, partially invasive, or invasive (Gasson 2012: 14)]. Typologies have also been developed that classify a neuroprosthesis according to whether it aids its human user to interact with a real physical environment using his or her natural physical body, augments or replaces the user's natural physical body (e.g., with robotic prosthetic limbs), or allows the user to sense and manipulate some virtual environment (Gladden 2015b).

Formulating Our Model for an Ontology of Neuroprosthetics

Here we propose a model for classifying and understanding neuroprosthetic devices especially in their role of integrating human beings into digital ecosystems, economies and information systems. The model comprises two main dimensions, of which one (impact) is further subdivided into two sub-dimensions (new capacities and detriments).

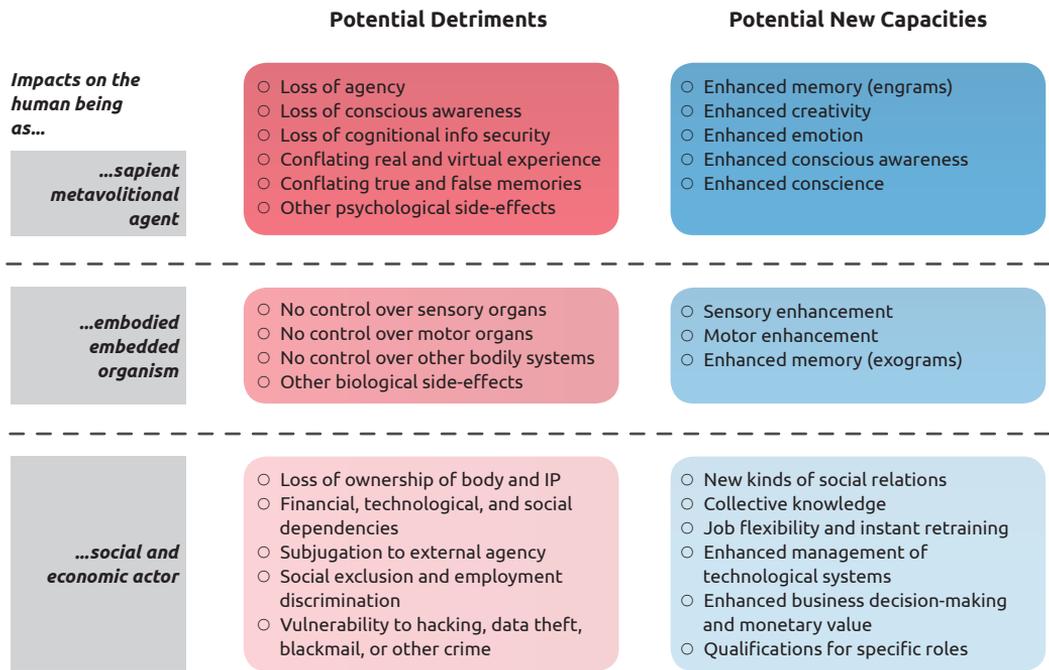
Roles of the Human User

A neuroprosthetic device affects its human user as viewed on three levels: 1) the human being as a sapient metavolitional agent, a unitary mind that possesses its own conscious awareness, memory, volition, and conscience—or "metavolitionality" (Gladden 2015d; Calverley 2008)—2) the human being as an embodied organism that inhabits and can sense and manipulate a particular environment through the use of its body; and 3) the human being as a social and economic actor who interacts with others to form social relationships and to produce, exchange, and consume goods and services.

Impact: Potential New Capacities and Detriments

At each of these three levels, a neuroprosthetic device can create for its user either new opportunities and advantages, new threats and disadvantages, or both. Typically a neuroprosthetic device creates new opportunities for its user to participate in socioeconomic interaction and informational ecosystems by providing some new cognitive, sensory, or motor capacity. Disadvantages may take the form of a new dependency on some external resource, the loss of a previously existing capability, a security vulnerability, or some other detriment. Because a neuroprosthetic device's creation of new capacities can be independent of its creation of detriments, these elements comprise two different dimensions; however, it is simpler to treat them as two sub-dimensions of a single larger dimension, the device's "impact".

Figure 1. A multidimensional model of the impacts of neuroprosthetic devices on individual users



Impacts Captured by Our Model

Below we present specific capacities and detriments that neuroprosthetics are expected to create for their users at the three levels of the human being as 1) sapient metavolitional agent, 2) embodied embedded organism, and 3) social and economic actor. These items constitute a broad universe of expected possible impacts identified by scholars; any one neuroprosthesis may generate only a small number of these effects, if any.

Impacts on the User as Sapient Metavolitional Agent

Neuroprosthetic devices may affect their users’ cognitive processes in ways that positively or negatively impact the ability of such persons to participate in socioeconomic interaction and informational ecosystems.

New capacities provided by neuroprosthetics may include:

- *Enhanced memory, skills, and knowledge stored within the mind (engrams)*. Building on current technologies tested in mice, future neuroprosthetics may offer human users the ability to create, alter, or weaken memories stored in their brains' natural memory systems in the form of engrams (Han, Kushner, Yiu, Hsiang, Buch, Waisman, Bontempi, Neve, Frankland, & Jossely 2009; Ramirez, Liu, Lin, Suh, Pignatelli, Redondo, Ryan, & Tonegawa 2013; McGee 2008; Warwick 2014: 267). This could potentially be used not only to affect a user's declarative knowledge but also to enhance motor skills or reduce learned fears.
- *Enhanced creativity*. A neuroprosthetic device may be able to enhance a mind's powers of imagination and creativity (Gasson 2012: 23–24) by facilitating processes that contribute to creativity, such as stimulating mental associations between unrelated items. Anecdotal increases in creativity have been reported to result after the use of neuroprosthetics for deep brain stimulation (Cosgrove 2004; Gasson 2012).
- *Enhanced emotion*. A neuroprosthetic device might provide its user with more desirable emotional dynamics (McGee 2008: 217). Effects on emotion have already been seen in devices used, e.g., for deep brain stimulation (Kraemer 2011).
- *Enhanced conscious awareness*. Research is being undertaken to develop neuroprosthetics that would allow the human mind to, for example, extend its periods of attentiveness and limit the need for periodic reductions in consciousness (i.e., sleep) (Kourany 2013: 992–93).
- *Enhanced conscience*. One's conscience can be understood as one's set of metavolitions, or desires about the kinds of volitions that one wishes to possess (Calverley 2008; Gladden 2015d); insofar as a neural implant enhances processes of memory and emotion (Calverley 2008: 528–34) that allow for the development of the conscience, it may enhance one's ability to develop, discern, and follow one's conscience.

New impairments generated by neuroprosthetics at the level of their user's internal mental processes may include:

- *Loss of agency*. A neuroprosthetic device may damage the brain or disrupt its activity in a way that reduces or eliminates the ability of its human user to possess and exercise agency (McGee 2008: 217). Moreover, the knowledge that this can occur may lead users to doubt whether their volitions are really "their own"—an effect that has been seen with neuroprosthetics used for deep brain stimulation (Kraemer: 2011).
- *Loss of conscious awareness*. A neuroprosthetic device may diminish the quality or extent of its user's conscious awareness, e.g., by inducing daydreaming or increasing the required amount of sleep. A neuroprosthesis could potentially even destroy its user's capacity for conscious awareness (e.g., by inducing a coma) but

- without causing the death of his or her biological organism (Gladden 2015d).
- *Loss of information security for internal cognitive processes.* A neuroprosthetic device may compromise the confidentiality, integrity, or availability of information contained within its user's mental activities (such as perception, memory, volition or imagination), either by altering or destroying information, making it inaccessible to the user, or making it accessible to unauthorized parties (McGee 2008: 217; Gladden 2015d; Gladden 2015c).
 - *Inability to distinguish a real from a virtual ongoing experience.* If a neuroprosthesis alters or replaces its user's sensory perceptions, it may make it impossible for the user to know which (if any) of the sense data that he or she is experiencing correspond to some actual element of an external physical environment and which are "virtual" or simply "false" (McGee 2008: 221; Gladden 2015d).
 - *Inability to distinguish true from false memories.* If a neuroprosthetic device is able to create, alter, or destroy engrams within its user's brain, it may be impossible for a user to know which of his or her apparent memories are "true" and which are "false" (i.e., distorted or purposefully fabricated) (Ramirez et al. 2013).
 - *Other psychological side effects.* The brain may undergo potentially harmful and unpredictable structural and behavioral changes as it adapts to the presence, capacities, and activities of a neuroprosthesis (McGee 2008: 215–16; Koops & Leenes 2012: 125, 130). These effects may include new kinds of neuroses, psychoses, and other disorders unique to users of neuroprosthetics.

Impacts on the User as Embodied Embedded Organism Interacting with an Environment

Neuroprosthetic devices may affect the ways in which their users sense, manipulate, and occupy their environment through the interface of a physical or virtual body. New capacities provided might include:

- *Sensory enhancement.* A neuroprosthetic device may allow its user to sense his or her physical or virtual environment in new ways, either by acquiring new kinds of raw sense data or new modes or abilities for processing, manipulating, and interpreting sense data (Warwick 2014: 267; McGee 2008: 214; Koops & Leenes 2012: 120, 126).
- *Motor enhancement.* A neuroprosthetic device may give users new ways of manipulating physical or virtual environments through their bodies (McGee 2008: 213; Warwick 2014: 266). It may grant enhanced control over one's existing biological body, expand one's body to incorporate new devices (such as an exoskeleton or vehicle) through body schema engineering (Gladden 2015b), or allow the user to control external networked physical systems such as drones or 3D printers or virtual systems or phenomena within an immersive cyberworld.

- *Enhanced memory, skills, and knowledge accessible through sensory organs (exograms)*. A neuroprosthetic device may give its user access to external data-storage sites whose contents can be "played back" to the user's conscious awareness through his or her sensory organs or to real-time streams of sense data that augment or replace one's natural sense data (Koops & Leenes 2012: 115, 120, 126). The ability to record and play back one's own sense data could provide perfect audiovisual memory of one's experiences (McGee 2008: 217).

New impairments generated by neuroprosthetics at the level of their users' physical or virtual bodily interfaces with their environments might include:

- *Loss of control over sensory organs*. A neuroprosthetic device may deny a user direct control over his or her sensory organs (Koops & Leenes 2012: 130). Technologically mediated sensory systems may be subject to noise, malfunctions, and manipulation or forced sensory deprivation or overload occurring at the hands of "sense hackers" (Gladden 2015c: 201–02).
- *Loss of control over motor organs*. A neuroprosthetic device may impede a user's control over his or her motor organs (Gasson 2012: 14–16). The user's body may no longer be capable, e.g., of speech or movement, or the control over one's speech or movements may be assumed by some external agency.
- *Loss of control over other bodily systems*. A neuroprosthetic device may impact the functioning of internal bodily processes such as respiration, cardiac activity, digestion, hormonal activity, and other processes that are already affected by existing implantable medical devices (McGee 2008: 209; Gasson 2012: 12–16).
- *Other biological side effects*. A neuroprosthetic device may be constructed from components that are toxic or deteriorate in the body (McGee 2008: 213–16), may be rejected by its host, or may be subject to mechanical, electronic, or software failures that harm their host's organism.

Impacts on the User as Social and Economic Actor

Neuroprosthetic devices may affect the ways in which their users connect to, participate in, contribute to, and are influenced by social relationships and structures and economic networks and exchange. New capacities provided might include:

- *Ability to participate in new kinds of social relations*. A neuroprosthetic device may grant the ability to participate in new kinds of technologically mediated social relations and structures that were previously impossible, perhaps including new forms of merged agency (McGee 2008: 216; Koops & Leenes 2012: 125, 132) or cybernetic networks with utopian (or dystopian) characteristics (Gladden 2015d).

- *Ability to share collective knowledge, skills, and wisdom.* Neuroprosthetics may link users in a way that forms communication and information systems (McGee 2008: 214; Koops & Leenes 2012: 128–29; Gasson 2012: 24) that can generate greater collective knowledge, skills, and wisdom than are possessed by any individual member of the system (Wiener 1961: loc. 3070ff., 3149ff.; Gladden 2015d).
- *Enhanced job flexibility and instant retraining.* By facilitating the creation, alteration, and deletion of information stored in engrams or exograms, a neuroprosthetic device may allow a user to download new knowledge or skills or instantly establish relationships for use in a new job (Koops & Leenes, 2012: 126).
- *Enhanced ability to manage complex technological systems.* By providing a direct interface to external computers and mediating its user’s interaction with them (McGee 2008: 210), a neuroprosthesis may grant an enhanced ability to manage complex technological systems, e.g., for the production or provisioning of goods or services (McGee 2008: 214–15; Gladden 2015b).
- *Enhanced business decision-making and monetary value.* By performing data mining to uncover novel knowledge, executing other forms of data analysis, offering recommendations, and alerting the user to potential cognitive biases, a neuroprosthesis may enhance its user’s ability to execute rapid and effective business-related decisions and transactions (Koops & Leenes 2012: 119). Moreover, by storing cryptocurrency keys, a neuroprosthesis may allow its user to store money directly within his or her brain for use on demand (Gladden 2015a).
- *Qualifications for specific professions and roles.* Neuroprosthetic devices may initially provide persons with abilities that enhance job performance in particular fields (Koops & Leenes 2012: 131–32) such as computer programming, art, architecture, music, economics, medicine, information science, e-sports, information security, law enforcement, and the military; as expectations for employees’ neural integration into workplace systems grow, possession of neuroprosthetic devices may become a requirement for employment in some professions (McGee 2008: 211, 214–15; Warwick 2014: 269).

New impairments generated by neuroprosthetic devices at the level of their users’ socioeconomic relationships and activity might include:

- *Loss of ownership of one’s body and intellectual property.* A neuroprosthetic device that is leased would not belong to its human user, and even a neuroprosthesis that has been purchased could potentially be subject to seizure in some circumstances (e.g., bankruptcy). Depending on the leasing or licensing terms, intellectual property produced by a neuroprosthetic device’s user (including thoughts, memories, or speech) may be partly or wholly owned by the device’s manufacturer or provider (Gladden 2015d; Gladden 2015c: 164).

- *Creation of financial, technological or social dependencies.* The user of a neuroprosthetic device may no longer be able to function effectively without the device (Koops & Leenes 2012: 125) and may become dependent on its manufacturer for hardware maintenance, software updates, and data security and on specialised medical care providers for diagnostics and treatment relating to the device (McGee 2008: 213). A user may require regular device upgrades in order to remain competitive in some jobs. High switching costs may make it impractical to shift to a competitor's device after a user has installed an implant and committed to its manufacturer's digital ecosystem.
- *Subjugation of the user to external agency.* Instead of merely impeding its user's ability to possess and exercise agency, a neuroprosthesis may subject its user to control by some external agency. This could occur, e.g., if the user's memories, emotions, or volitions were manipulated by means of the device (Gasson 2012: 15–16) or if the user joined with other minds to create a new form of social entity that possesses some shared agency (McGee, 2008: 216).
- *Social exclusion and employment discrimination.* The use of detectable neuroprosthetics may result in shunning or mistreatment of users (Koops & Leenes 2012: 124–25). Users of advanced neuroprosthetics may lose the ability or desire to communicate with human beings who lack such devices, thereby fragmenting human societies (McGee 2008: 214–16; Warwick 2014: 271) and possibly weakening users' solidarity with other human beings (Koops & Leenes 2012: 127). Possession of some kinds of neuroprosthetic devices may exclude their users from employment in roles where "natural," unmodified workers are considered desirable or even required (e.g., for liability or security reasons).
- *Vulnerability to data theft, blackmail, and extortion.* A hacker, computer virus, or other agent may be able to steal data contained in a neuroprosthesis or use it to gather personal data (potentially including the contents of thoughts, memories, or sensory experiences) (McGee 2008: 217; Koops & Leenes 2012: 117, 130; Gasson 2012: 21; Gladden 2015: 167–68) that could be used for blackmail, extortion, corporate espionage, or terrorism.

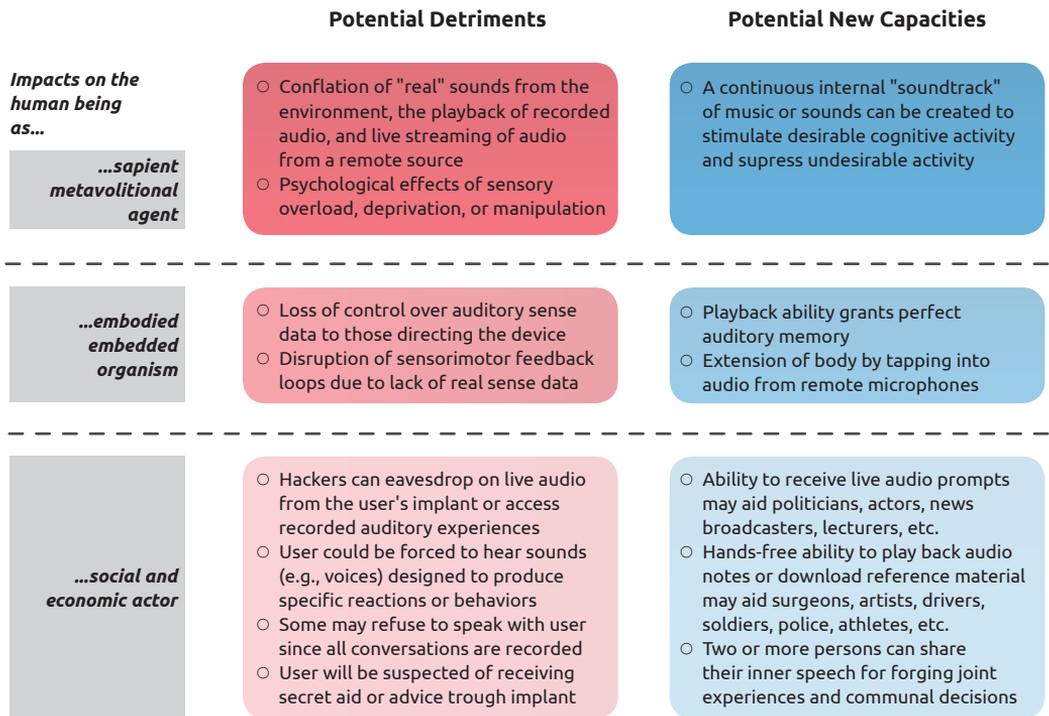
Applying the Model: Toward a New Typology of Neuroprosthetics

As a test case, we can use this model to analyse one kind of neuroprosthetic device that is expected to become available in the future: a cochlear implant with audio recording, playback, upload, download, and live streaming capabilities (Koops & Leenes 2012; McGee 2008; Gladden 2015d). Everything that its user hears would be recorded for later playback on demand. Instead of simply conveying the "real" sounds produced

by the physical environment, those sounds can be augmented or replaced by other audio that is stored in or transmitted to the device. Potential capacities and impairments created for the user of such a device are identified in Figure 2 below.

As can be seen from this example, the model does not yield a single quantitative "impact score" for each of the three levels but rather uses qualitative descriptions to capture a complex set of impacts. This model delineates a device ontology that can form the basis of further reflection on and analysis of a neuroprosthetic device's impact from both cybernetic, phenomenological, and existentialist perspectives. By allowing neuroprosthetic devices with similar characteristics to be identified and grouped, it can also serve as the basis of new typologies for neurotechnologies.

Figure 2. The model applied to analyse impacts of a particular auditory neuroprosthesis



Conclusion

Ongoing advances in neuroprosthetics are expected to yield a diverse range of new technologies with the potential to dramatically reshape a human being's internal mental life, his or her bodily existence and interaction with the environment, and his or her participation in social and economic networks and activity. The new capacities and impairments that such technologies provide may allow human beings to physically and virtually inhabit digital ecosystems and interact socially in ways so revolutionary that they can best be understood as "posthuman."

The model developed in this text for understanding these impacts of neuroprosthetic devices is already being elaborated in the specific context of information security to provide a framework for future research and practice in that field (Gladden 2015c). By further refining and applying the model in other contexts, we hope that it will be possible for engineers, ethicists, policymakers, and consumers to better understand how particular kinds of neuroprosthetic devices may contribute to the development of new digital ecosystems that can be a powerful venue for the growth, liberation, and empowerment—or oppression and dehumanization—of the human beings of the future.

References

- Calverley D.J., (2008), "Imagining a non-biological machine as a legal person", *AI & SOCIETY* 22(4), 523–37.
- Cosgrove G.R., (2004), Session 6: Neuroscience, brain, and behavior V: Deep brain stimulation. Meeting of the President's Council on Bioethics, Washington, DC, June 24–25, 2004. <https://bioethicsarchive.georgetown.edu/pcbe/transcripts/june04/session6.html>, accessed June 12, 2015.
- Ferrando F., (2013), "Posthumanism, transhumanism, antihumanism, metahumanism, and new materialisms: Differences and relations", *Existenz: An International Journal in Philosophy, Religion, Politics, and the Arts* 8(2), 26–32.
- Gasson M.N., (2012), *Human ICT implants: From restorative application to human enhancement* In M.N. Gasson, E. Kosta, & D.M. Bowman (eds.), *Human ICT Implants: Technical, Legal and Ethical Considerations*, T. M. C. Asser Press, 11–28.
- Gladden M.E., (2015), "Cryptocurrency with a conscience: Using artificial intelligence to develop money that advances human ethical values", *Ethics in Economic Life*, Uniwersytet Łódzki, May 8, 2015.

- Gladden M.E., (2015), Cybershells, shapeshifting, and neuroprosthetics: Video games as tools for posthuman 'body schema (re)engineering.' Ogólnopolska Konferencja Naukowa Dyskursy Gier Wideo, AGH, Kraków, June 6, 2015.
- Gladden M.E., (2015), *The Handbook of Information Security for Advanced Neuroprosthetics*. Indianapolis: Synthypnion Academic.
- Gladden M.E., (2015), Tachikomantic domains: Utopian cyberspace as a 'contingent heaven' for humans, robots, and hybrid intelligences. His Master's Voice: Utopias and Dystopias in Audiovisual Culture, Uniwersytet Jagielloński, March 24, 2015.
- Gripsrud M. & Hjorthol R., (2012), "Working on the train: From 'dead time' to productive and vital time", *Transportation* 39(5), 941–56.
- Han J.-H., Kushner S.A., Yiu A.P., Hsiang H.-W. Buch, T. Waisman, A. Bontempi, B. Neve, R.L. Frankland, P.W. & Josselyn S.A., (2009), "Selective erasure of a fear memory", *Science* 323(5920), 1492–96.
- Koops B.-J. & Leenes R., (2012), *Cheating with implants: Implications of the hidden information advantage of bionic ears and eyes* In M.N. Gasson, E. Kosta, & D.M. Bowman (eds.), *Human ICT Implants: Technical, Legal and Ethical Considerations*, T. M. C. Asser Press, 113–134.
- Kourany J.A., (2013), "Human enhancement: Making the debate more Productive", *Erkenntnis* 79(5), 981–98.
- Kraemer F., (2011), "Me, myself and my brain implant: Deep brain stimulation raises questions of personal authenticity and alienation", *Neuroethics* 6(3), 483–97.
- Lebedev M., (2014), "Brain-machine interfaces: An overview", *Translational Neuroscience* 5(1), 99–110.
- McGee E.M., (2008), *Bioelectronics and implanted devices* In B. Gordijn & R. Chadwick (eds.), *Medical Enhancement and Posthumanity*, Springer Netherlands, 207–224.
- Ramirez S., Liu X., Lin P.-A., Suh J., Pignatelli M., Redondo R.L., Ryan T.J., & Tonegawa S., (2013), "Creating a false memory in the hippocampus", *Science* 341(6144), 387–91.
- Rao R.P.N., Stocco A., Bryan M., Sarma D., Youngquist T.M., Wu J., & Prat C.S., (2014), "A direct brain-to-brain interface in humans", *PLoS ONE* 9(11).
- Shih J., (2004), "Project time in Silicon Valley", *Qualitative Sociology* 27(2), 223–45.
- Warwick K., (2014), "The cyborg revolution", *Nanoethics* 8, 263–73.
- Wiener N., (2015), *Cybernetics: Or Control and Communication in the Animal and the Machine*, second edition. Cambridge, Massachusetts: The MIT Press, 1961 (Quid Pro ebook edition for Kindle, 2015).