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Communication, Machines & Human Augmentics

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Abstract
This essay reformulates the question of human augmentation as a problem of advanced human-machine communication, theorizing that such communication implies robust artificial intelligence and necessitates understanding the relational role new technologies play in human-machine communication. We focus on the questions, "When do electronic tools cease to be 'simply' tools, and become meaningfully part of ourselves," and, "When might we think of these tools as augmenting our selves, rather than simply amplifying our capabilities?" These questions, already important to the medical and rehabilitative fields, loom larger with increasing commodification of pervasive augmentation technologies, and indicate the verge on which human-machine communication now finds itself. Through analyses of human and machine agency, mediated through a theory of close human-machine communication, we argue that the critical element in discussions of human-machine communication is an increase in sense of agency, extending the traditional human-computer interface dictum to provide an internal locus of control.

Keywords
Human Augmentics, Human-Machine Communication, Human-Computer Interaction, Agency, Sense of Agency

Humans have long used tools and technology to augment human capabilities and senses. From using a lever to move a large, heavy object to using lenses to correct vision or see at a distance or up close, from using a watch to tell the time to using writing (and later electricity and electromagnetic waves) to communicate at a distance (and store communication, too), the augmentation of human capabilities has in every instance led to profound changes in knowledge, behavior, communication and culture.[1] The miniaturization of technology during the late 20th and early 21st centuries has meant that augmentation has increasingly occurred with technologies that are not only built on a smaller scale but that are also mobile and personal. Mobile media such as phones, GPS trackers, fitness bands, and other devices, have become ubiquitous in most parts of the world and there is at least one mobile connection for every person on the planet,[2] and are on or about our bodies almost always. Noting the link between modern technologies and the history of media, Adriana de Souza e Silva and Jordan Frith wrote, "for at least two centuries, individuals have used mobile media, such as books, Walkmans, iPods and mobile phones as technological filters to manage their interactions with otherwise uncontrollable surroundings."[3]

It follows from de Souza e Silva's and Frith's observation that as technology is increasingly miniaturized and networked, at some point electronic tools cease to be "simply" tools or "filters," and become meaningfully part of ourselves, augmenting the self, rather than amplifying our capabilities. They are part of the milieu, the environment that interfaces and mediates between us and the world around us. They become what Mark Weiser and John Seely Brown have termed "calm technologies,"[4] ones that, according to Anne Galloway's interpretation of the term are "between the periphery and center of our attention, outside of conscious awareness (but not completely absent) until we actively

[1] See Harold Adams Innis, *The Bias of Communication* (Toronto: University of Toronto Press, 1964); James W. Carey, *Communication as Culture: Essays on Media and Society* (New York: Routledge, 1992).

[2] Joss Gillet, "Measuring Mobile Penetration," *GSMA Intelligence* (22 May 2014). Available online at https://www.gsmaintelligence.com/research/2014/05/measuring-mobile-penetration/430/. Last accessed April 30, 2016.

[3] Adriana De Souza e Silva and Jordan Frith, "Locational Privacy in Public Spaces: Media Discourses on Location-Aware Mobile Technologies," *Communication, Culture, & Critique* 3(4) (2010): 505.

[4] Mark Weiser and John Seely Brown, "The coming age of calm technology," (05 October 1996). Available online at https://www.cs.ucsb.edu/~ebelding/courses/284/papers/calm.pdf. Last accessed June 30, 2016.

focus" on them.[5] In her essay on the cultural implications of ubiquitous computing she goes on to note that these technologies "would be so embedded, so pervasive, that (they) could be taken for granted."[6] They are less lever and more muscle, it might be said; they cease to be merely "filters to manage… interactions" and become interactive, engaging with users and the world, and mediating users' engagements with the world.

The increasing commodification and commercialization of ubiquitous, pervasive augmentation technologies is leading to "a restructuring and re-bordering of interaction with the world around us… as we increasingly communicate, willingly or unknowingly, with machines."[7] Indeed, the verge on which human-machine communication now finds itself[8] and its intersection with wearable and Internet of Things technologies should cause us to focus critically on these technological augmentations, which we call Human Augmentics. Through analyses of human and machine agency, interposed through a theory of close human-machine communication, we argue that the critical element in discussions of human-machine communication is an increase in sense of agency, extending the traditional human-computer interface dictum to provide an internal locus of control, and is the defining feature of Human Augmentics.

Foundations

Philosophical discussions concerning exceeding human physical and cognitive limits with technology have been ongoing since at least the publication of Aldous Huxley's Brave New World.[9] The term "transhumanism," coined by Julian Huxley,[10] as well as the terms "posthuman" and "cyborg" served as umbrellas denoting ideas and efforts in the 1950s and beyond to advance human evolution through the use of technology and medicine. The history and philosophical threads pertaining to transhumanism are well described in The Transhumanist

[5] Anne Galloway, "Intimations of Everyday Life: Ubiquitous computing and the city," *Cultural Studies* 18(2-3) (2010): 388.
[6] Ibid., 388.
[7] Steve Jones, "People, things, memory and human-machine communication," *International Journal of Media and Cultural Politics* 10(3) (2014): 255.
[8] David J. Gunkel, "Communication and Artificial Intelligence: Opportunities and Challenges for the 21st Century," *Communication +1*, 1(1) (2012); Andrea Guzman, *Imagining the Voice in the Machine: The Ontology of Digital Social Agents.* Doctoral dissertation, University of Illinois at Chicago (2015).
[9] Aldous Huxley, *Brave New World* (San Bernadino, CA: The Borgo Press, 1989 [1932]).
[10] Julian Huxley, *New Bottles for New Wine* (New York: Harper, 1957).

FAQ by Bostrom.[11] More recently still, the Quantified Self (QS) movement has emphasized self-tracking through individual data collection using wearable technologies and sensors.[12] The persuasive elements of self tracking have drawn on work by B.J. Fogg who coined the term "captology" to denote the connection between computing and persuasion.[13] In 2011 Robert Kenyon and Jason Leigh, in "Human Augmentics: Augmenting Human Evolution," lay out a largely utopian view of Human Augmentics, describing what is essentially a merging of transhumanism, captology and QS, defining the term Human Augmentics as referring to "technologies for expanding the capabilities and characteristics of humans," or as they put it another way, as "the driving force in the non-biological evolution of human."[14] Human Augmentics technologies, they believe, are meant to compensate for natural cognitive and physiological limitations "so that our abilities can be expanded."[15]

Kenyon and Leigh also suggested that Human Augmentics contains a distinguishing philosophical goal focused on increasing quality of life over extending life while offering prescriptive criteria Human Augmentics must meet; particularly that Human Augmentics devices need to have standard open protocols and be open access so that devices and data can be easily integrated. They proposed three unique characteristics of Human Augmentics. First, as non-biological human evolution implies, Human Augmentics are strictly mechanical and electrical technologies that do not involve chemicals or other biological modifications to achieve goals. However, it does include interfacing directly with internal and external biological systems. For example, a device interfacing with the brain, which allows an individual to operate a prosthetic arm would be considered Human Augmentics. Second, wide distribution of Human Augmentics creates ecosystems by bringing devices and users into a network, possibly

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[11]Nick Bostrom, "The Transhumanist FAQ", 2003. Retrieved online at http://www.nickbostrom.com/views/transhumanist.pdf. Last accessed April 11, 2016.

[12] Deborah Lupton. "M-health and health promotion: The digital cyborg and surveillance society," *Social Theory & Health*, 10(3): 2012; Deborah Lupton. "Quantifying the body: Monitoring and measuring health in the age of mHealth technologies," *Critical Public Health*, 23 (2013); Deborah Lupton. "Self-tracking Modes: Reflexive Self-monitoring and Data Practices," Conference paper, 2014. Retrived online at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2483549. Last accessed April 11, 2016.

[13] B. J. Fogg, *Persuasive Technology: Using Computers to Change What We Think and Do* (San Francisco: Morgan Kauffman Publishers, 2003).

[14] Robert Kenyon, and Jason Leigh, Human Augmentics: Augmenting Human Evolution," *IEEE Engineering Medicine Biology Conference* 2011, Boston, MA, USA: 6758.

[15] Ibid., 6758.

facilitated by cloud computing and body area networks, that constitute a flexible, ever adapting feedback system. Third, technologies such as wearable devices, virtual reality systems, mobile computing, cloud computing, robots, and other Human Augmentics devices will increasingly converge. Smart phones and Google Glass offer examples that are already in use but the foundation of Human Augmentics rests on these technologies being made available to all with the potential for inter-technological communication.

While Kenyon and Leigh successfully began the process of conceptualizing Human Augmentics and provide fertile suggestions for research, their article acts primarily as a vision statement, and a largely utopian one at that. It lacks conceptual clarity, historical context, and criticality. While Kenyon and Leigh make reference to Ray Kurzweil and his notion of the singularity[16] they do so only to distinguish the goal of Human Augmentics as a means of living better rather than living forever. They implicitly acknowledge other human augmentation concepts but fail to fully account for the deep historical roots that inform Kurzweil, their own work, and human augmentation more broadly. Much prior scholarship has considered and experimented with the ways that technologies extend human capabilities. The trope of augmentation is especially pertinent in computer science. As early as the 1960's Doug Engelbart was already proposing a framework for intellectual augmentation which Cassandra Xia & Pattie Maes argued was especially relevant when considering the way software and other technological artifacts could augment human intellect.[17] There is also a need to acknowledge work being done in a similar vein across different disciplines, albeit work that uses different terms than transhumanism, cyborg theory or Human Augmentics. For instance, the terms eHealth[18] and mHealth[19] are increasingly used in health fields to describe electronic and mobile devices that are meant to increase health outcomes by helping patients adhere to medical guidance.

Kenyon and Leigh frame Human Augmentics in largely apolitical terms, using phrases like "expand capabilities" normatively. Critical issues associated

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16 Ray Kurzweil, *The Singularity Is Near: When Humans Transcend Biology* (New York: Penguin Books, 2006).

17 Cassandra Xia and Pattie Maes, "The design of artifacts for augmenting intellect." In Proc. AH, ACM (2013). Available online at http://hdl.handle.net/1721.1/79875. Last accessed April 30, 2016.

18 Vincenzo Della Mea, "What is e-Health: The Death of Telemedicine?" *Journal of Medical Internet Research 3*(2):e22. Available online at http://www.jmir.org/2001/2/e22/. Last accessed April 30, 2016.

19 Sasan Adibi (Ed.), *Mobile Health: A Technology Road Map* (Heidelberg: Springer, 2015).

with notions like (dis)ability and the way that expanding capabilities may not necessarily be equated with living well are not addressed. How is living well defined and who defines it? Who determines what constitutes ability and extending capability? Their article gives a brief acknowledgement that living well should mean living well for everyone but it makes no acknowledgment that the very idea of suggesting that technologies be used to enhance well-being is anything but a neutral stance. The normative tone of their article is best illustrated by their imprecise use of the term "rehabilitation." Most commonly rehabilitation is defined as re-enabling, and in a medical context rehabilitation is the process of restoring lost faculties, lost abilities, or lost health (for instance, hearing aids for patients who have suffered progressive age-related hearing loss). By contrast habilitation is the process of developing faculties or abilities that are expected, but for some reason are not and have never been present (for instance, hearing aids for infants and very young children who have never experienced the expected level of hearing sensitivity.) Strictly speaking, habilitation could also mean the development of faculties or abilities beyond an expected level, or which effectively are not expected to exist (for instance, hearing aids which extend the frequency of human hearing above the expected range of 20 KHz.) However, it might be appropriate to use a qualifying prefix (super-habilitation, perhaps) to distinguish such usage.

Our goal is to illuminate Human Augmentics' reliance on notions of agency and the central role communication plays in its technological formation and thereby illustrate its potential as a useful, critical theoretical tool with which to understand the convergence of human and machine agency. In our view what sets apart Human Augmentics from other efforts to enhance humans is the articulation of human and machine, through the combination of sensors and sensing and reliance on human-machine communication, that articulates in turn with human agency.

Maxwell Mehlman, in the introduction to his book The Price of Perfection, asked many trenchant questions concerning the ethics and politics of human chemical, medical and genetic enhancement, but concluded it by writing that "we cannot stop (enhancement), nor should we."[20] Mehlman, however, moves a step closer to a notion of agency in the book's discussion of athletic performance, citing the President's Council on Bioethics that "distinguishes between 'intelligible agency' or 'getting better because of what we do'... and 'unintelligible agency,' or 'getting better because of what is done to us.'"[21] He critiques these as arbitrary distinctions, tied only to the effort a human makes, and

[20] Maxwell Mehlman, *The Price of Perfection: Individualism and Society in the Era of Biomedical Enhancement* (Baltimore: The Johns Hopkins University Press, 2009), 254.
[21] Ibid., 65.

does not further discuss agency. Drawing on frameworks developed by Russell and Norvig, and Norman[22]we believe a human's agency increases when a device increases his or her ability to perceive the world, to affect the world, to model the world, or to manage goals. Drawing further on Norman, a human's sense of agency increases when no device at his or her command imposes a mismatch between intent and allowable actions, or an undue burden on understanding the state of the tool. A path to such technologies requires intelligent devices of sufficient sophistication to anticipate and respond to our needs as smoothly as do our limbs, as well as advanced sensory feedback to present information as smoothly as our native senses.

Agency in Relation to Socio-Material-Technical Forces

For our argument, we locate agency and sense of agency in the intra and interpersonal levels of communication between humans and devices as opposed to thinking through issues of agency in larger socio-material contexts. We admit that we cannot separate agency entirely from larger contexts, but we can focus on parts of them. The work necessarily reduces the field of view to focus on a limited slice of the socio-technical reality that makes up Human Augmentics, leaving a challenge we hope will be taken up by other scholars in the future. We do not contend to make broad claims about the general state of agency in this paper, but we do argue that using specific definitions of agency and sense of agency as constructs can help us think through what is unique about human-machine communication arising with Human Augmentics. Still, being aware of the likely pushback our use of agency will invoke, it is worthwhile to provide some context and defense of our position.

With changes in technology and social theory, there has been a quick shift in understanding agency that rejects the idea "that autonomous agency is contained within individuals and is a distinguishing capacity of the human."[23] Proponents of Actor-Network Theory champion a notion of agency that grants equal status to humans and non-humans in a largely symmetric network where agency is produced in the interactions between actors rather than something inherently stable within actors.[24] Summarizing Michel Callon and John Law's

[22] Stuart Russell, Peter Norvig. *Artificial Intelligence: A modern approach.* (Prentice-Hall, Englewood Cliffs, 1995); Don Norman. T*he design of everyday things* (Revised and expanded edition.) (New York: Basic Books, 2013).

[23] Lucy A. Suchman, *Human-machine reconfigurations: plans and situated actions* (2nd ed.) (Cambridge: Cambridge University Press, 2007), 211.

[24] Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory* (Oxford: Oxford University Press, 2005).

theorization of the “hybrid collective”[25] Owain Jones and Paul Cloke state, “agency is viewed as being spun between different actors (or ‘actants’) rather than manifested as solitary or unitary intent and it is decoupled from subject – object distinctions. The hybrids are then seen as mobilized and assembled into associative networks in which agency represents the collective capacity for action by humans and non-human.”[26] Echoing the non-binary, symmetrical, and interactive formation of agency, Mark Hansen argues that “we must rethink agency as the effect of global patterns of activity across scales of networks, where absolutely no privilege is given to any particular individual or node, to any level of complexity” because “agency is *resolutely not* the prerogative of privileged individual actors.”[27]

While reconfigurations of agency have helped push social theory in more critical directions, better accounting for the complexity and entanglement that displace control from individuals within the power relations of a larger socio-technical-material world, their absolute emphasis on symmetry and non-binary relationships denies the potential for individual resistance. In order to get from notions of autonomous human agency to agency as produced through networks of symmetric interaction, ANT suspends “the concepts of human intentionality and creativity.”[28] According to Victor Kaptelinin and Bonnie Nardi, the notion of agency articulated by ANT, while especially useful given advances in AI technologies, is still too limiting as it denies the “particular potency of human agency.”[29]

In their formulation of agency, Victor Kaptelinin and Bonnie Nardi suggest that agency can be defined as the “ability and need to act,” later narrowing the definition by adding “acting is producing an effect according to an intention.”[30] This definition is similar to the definition we propose in the next section, but pertinent to the current conversation, their definition leads them to identify two types of needs that precipitate action, biological and cultural. In their conceptualization, “artifacts are special agents that are the product of cultural

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[25] Michel Callon and John Law, “Agency and the Hybrid Collectif,” *South Atlantic Quarterly*, 94 (1995): 481-507.

[26] Owain Jones and Paul Cloke, “Non-Human Agencies: Trees in Place and Time,” in *Material Agency: Toward a Non-Anthropocentric Approach*, eds. Carl Knappett and Lambros Malafouris (New York: Springer Press, 2008), 84 - 85.

[27] Mark B.N. Hansen, *Feed-Forward: On the Future of Twenty-First Century Media.* (Chicago: University of Chicago Press, 2015), 2.

[28] Victor Kaptelinin and Bonnie A. Nardi, *Acting with Technology: Activity Theory and Interaction Design* (1st paperback ed.) (Cambridge: The MIT Press, 2009), 241.

[29] Ibid., 241.

[30] Ibid., 242.

needs. Humans have gained some control over our needs through the design and deployment of artifacts that embody our intentions and desires."[31] Moreover, and in line with our own conceptualization of the role of tools in increasingly agency, they state, "activity theory conceptualized the potency of human agency in part through the principle of mediation: tools empower in mediating between people and the world."[32] However, as more collaborator than mediator, Human Augmentics necessarily pushes us to think about the agency developed through emerging forms of human-machine communication in different ways.

Unraveling issues of agency is a complicated matter, one with profound implications on multiple levels. While there will always be social, political, and technical contexts to account for when considering the impact of technologies on human agency and visa versa, we choose to focus on agency as it arises at the intersection of humans and machines, where agency is co-constructed in intra and interpersonal communicative processes. While these forms of communication can never be entirely divorced from the larger socio-technical context – indeed, they arise within and are constrained by these contexts, we can provide one useful framework that focuses on those particular intersections. What the framework may give up in explanatory power on a systemic level, it makes up for by assessing a more intimate level of communication, one that is not just constrained by socio-technical contexts but also serves as an anchoring point shaping those contexts. Locating the argument at these levels of communication provides a meaningful model to extend work in Human-Machine Communication (HMC) that hinges on issues of agency.[33]

Humans, Agency and Machines

Although there is no universally agreed upon definition of agent or agency,[34] we draw on ideas from modern philosophy and computer science to define an agent

[31] Ibid., 248.
[32] Ibid., 248.
[33] David J. Gunkel, "Communication and Artificial Intelligence: Opportunities and Challenges for the 21st Century," *Communication +1*, 1(1) (2012); Andrea Guzman, *Imagining the Voice in the Machine: The Ontology of Digital Social Agents.* Doctoral dissertation, University of Illinois at Chicago (2015); Steve Jones, "People, things, memory and human-machine communication," *International Journal of Media and Cultural Politics* 10(3) (2014).
[34] Xabier E. Barandiaran, Ezequiel Di Paolo, and Marieke Rohde, "Defining agency: Individuality, normativity, asymmetry, and spatio-temporality in action," Adaptive Behavior 17, no. 5 (2009); Michael Wooldridge. *An introduction to multiagent systems*. (John Wiley & Sons, 2009).

as one which acts with a goal-oriented purpose or purposes, and agency as the ability to act *effectively* with respect to goals. We focus on this formulation of agency, not because it is the only conception of human agency, nor because it is a form of agency unique to human beings, but because it is a very useful framework for the discussion of the human relationship with the use, and more especially the design, of tools. In particular, this formulation captures through its focus on goals what Pickering[35] describes as the intentionality of humans, although as we shall describe below we do not reserve intentionality to humans but note its continuing extension into our tools through the field of artificial intelligence, and acknowledge its presence without further comment in the biological world. As well, the notion of effectivity captures a notion of power similar to the meaning of agency in practice theory as discussed by Kipnis,[36] Laidlaw,[37] and Ortner,[38] although considering the primary "larger structure" as the physical environment itself.

The philosophical work of Donald Davidson links actions, reasons, and reasoning, noting that when asked the reason for a particular action, people often respond with a description of the expected or intended result of the action itself.[39] Davidson claims that the expected result is itself the reason, which he formalizes as: An agent acts with intention if it is well-disposed toward (i.e., if it desires, wishes, has as a goal, or in general "has a pro-attitude" toward) certain classes of actions, and further believes that some particular action is a member of that class. Further, these broad classes of actions toward which an agent might have a pro-attitude are themselves results based. For example, one might desire light in a darkened room; thus, one would have a pro-attitude toward the broad class of actions expected to bring light, including: Flipping a light switch; opening curtains during a sunny day; lighting a fire in a fireplace, etc. The desire for light would, under Davidson's framework, be the reason for flipping a light switch.

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[35] Andrew Pickering, "The mangle of practice: Agency and emergence in the sociology of science," *American Journal of Sociology* (1993): 559-589.

[36] Andrew Kipnis, "Agency between humanism and posthumanism: Latour and his opponents," *HAU: Journal of Ethnographic Theory* 5.2 (2015): 43-58.

[37] James Laidlaw, "Agency and responsibility: perhaps you can have too much of a good thing," *Ordinary ethics: anthropology, language, and action* (2010): 143-164.

[38] Sherry B. Ortner, *Anthropology and social theory: Culture, power, and the acting subject* (Duke University Press, 2006).

[39] Donald Davidson, "Actions, reasons, and causes." *The Journal of Philosophy* 60, no. 23 (1963): 685-700.

Michael Bratman later sharpens this idea into the Belief-Desire-Intention framework,[40] where beliefs represent an agent's store of information about the world, desires represent an agent's desired configuration or configurations of the world, and intentions represent the finished or in-process planning that links beliefs and desires. In this framework, intentions and desires are both actions toward which an agent has pro-attitudes, but only intentions are "action-controlling." Whereas desires are any pro-attitude actions, even mutually conflicting actions, intentions are those pro-attitude actions which carry a level of commitment and which serve to pin or prune an agent's planning. While an agent might easily *desire* to spend the same sum of money several times over (an example of mutually conflicting desires), once an agent *intends* to spend a sum of money in a particular way, that sum is restricted for the purposes of further planning. Bratman later participated in the extension of his framework into the Belief-Desire-Intention ("BDI") model of intelligent software agents,[41] using similar definitions. However, the BDI model focuses on the internal states and actions of the agent, while saying little directly about the formation of beliefs.

Subsequent elaborations in computer science, and philosophy (such as enactivism[42]), have maintained focus on the internal states of the agent but also expanded and formalized a key idea: that agents are understood to be embodied in the world,[43] as well as holding desires, beliefs and intentions about the world.[44]

This formal elevation of the environment allows the analysis of the agent and environment as two components of a larger system, yielding a number of results. First, this separation leads to the idea of the agent and environment acting in a loop. The agent acts on the environment, which reacts (in accordance with its own rules) to the agent, which acts again on the environment, etc. Second, it calls attention to the boundary between the two, and processes at that boundary. The agent takes in information from the environment through sensors, and acts on the environment in an attempt to influence how it changes through effectors. Third,

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[40] Michael Bratman, *Intention, plans, and practical reason* (Harvard University Press: Cambridge, MA, 1987).

[41] Michael E. Bratman, David J. Israel, and Martha E. Pollack, "Plans and resource- bounded practical reasoning." *Computational intelligence* 4, no. 3 (1988): 349-355.

[42] Hanne De Jaegher and Ezequiel Di Paolo, "Participatory Sense-Making: An Enactive Approach to Social Cognition," *Phenomenology and the Cognitive Sciences* 6 (2007), 485-507.

[43] Strictly, embedded in an environment, for an agent may be a purely software construct embedded in a simulated world.

[44] Randall D. Beer, "A dynamical systems perspective on agent-environment interaction." *Artificial intelligence* 72, no. 1 (1995): 173-215; Rodney A. Brooks, "Intelligence without representation." *Artificial Intelligence* 47, no. 1 (1991).

with the conceptual boundaries between agent and environment cleanly drawn, it allows a more systemic conceptualization of Bratman's beliefs, desires, and intentions, specifically, that beliefs are the results of repeated sensing operations leading to an understanding of the environment; desires are configurations of the environment different from and preferable to the agent's current understanding; and intentions are hypothetical actions leading to those preferred environmental configurations. Finally, it leads to a concise and robust definition of an agent as, "a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future."[45] With emphasis placed on the agent, and with the response of the environment left implicit, the agent loop can be conceptualized concisely as:

- Sense - Agent receives information about the environment (possibly partial and imperfect) through its sensors;
- Understand - Agent incorporates that information (possibly imperfectly) into previous information to form beliefs about the world;
- Manage Goals - Agent generates intentional plans informed by its own goals and inflected by its current understanding of the environment (and of how the environment reacts) in order to bring about its desires;
- Act - Agent acts on the environment.[46]

This notion of a loop is intended to be a general framework. The precise mechanisms of sensing, environment modeling, goal formation/planning, and acting are intentionally unspecified in the artificial intelligence community, because not all agents share, *e.g.*, common sensing modalities (indeed, as we discuss below, even naturally occurring agents do not share such modalities) and to foster research into each step in the loop. This loop is not intended to be rigid or simplistic. While simple agents may in fact sense, *then* understand, *then* plan, *then* act, more sophisticated agents perform these processes concurrently, with information flowing along the direction of the loop. In particular, whether a vehicle is driven by a human or an autonomous computer, the controlling agent continuously and concurrently performs all those processes: sensory information is received in a constant stream, but does not halt while that information updates the agent's model of the world. Likewise, model updates do not halt while new models cause a revision of plans. However, the loop has a direction since an

[45] Stan Franklin, and Art Graesser, "Is it an Agent, or just a Program?: A Taxonomy for Autonomous Agents." In Intelligent agents III agent theories, architectures, and languages, pp. 21-35. (Springer Berlin Heidelberg, 1996.): 25.

[46] Stuart Russell, Peter Norvig, *Artificial Intelligence: A modern approach.* (Prentice-Hall, Englewood Cliffs, 1995).

agent's current understanding of the environment depends on current and past perceptions; an agent's current plans depend on the current understanding; and an agent's current action is selected in accordance with the current plan.

The partition of space into an agent embedded in an environment is conceptual, not absolute. In reality, human beings and physically embodied agents are part of an environment. In particular, agents may not (and in particular, humans do not) have perfect knowledge of their physical selves, but rely on perceptions and actions to determine their own true state. The conceptual partition is often drawn such that much of the agent's physical apparatus is sensed as though part of the environment, yet acts as though part of the agent.

As we focus on the individual processes of this loop, we show that enhancing a human agent's capability in any of these processes is tantamount to increasing his or her agency, i.e., the ability to act *effectively* with respect to goals. Devices which enhance human capabilities (and therefore agency) in this regard are tools. However, as we will discuss later, this increase of agency is not sufficient for a tool to be considered Human Augmentics. Consider the scenario of a vacationing traveler faced with navigating an unfamiliar city and having a rough itinerary: several specific locations must be visited; several tasks must be performed, though not necessarily at unique locations; and several more locations or tasks are optional. In this scenario, we discuss various devices intended to affect the multiple facets of the user's agency loop. For illustrative purposes only, we stipulate that these interactions are positive, which is to say, the devices function reliably, function as intended, and function without unintended consequence. We return later to cases where this oversimplification does not obtain.

Sensing represents movement of information from the environment to the agent. Sensory devices may enhance natural human senses (e.g., sight, hearing, etc.), or may map information not normally available to human beings onto those senses. In the context of our navigation scenario, an example of the former is a pair of field glasses, which enhance the range of human sight enabling the navigator to read street signs or addresses from a greater distance; an example of the latter is a haptic device using a tactile channel to provide persistent orientation information, constantly signaling true north, or constantly signaling the direction of the next turn or location on the itinerary.

Understanding represents the continual refinement of the agent's static and dynamic models of the world, that is, both as the world is at a point in time, and as the world might evolve based on particular actions or inaction. A tool relevant to the project of urban navigation which aids a human in understanding an environment is a simple street map: a codified, visually interpretable collection of past observations and measurements of a location (in this case, a city.) It is important to recognize that a map is not simply a list or collection of past perceptions by the self and/or others, but an organized integration of past perceptions, from different but related locations and at different times; no individual observation is necessary to the map, but each individual observation enhances it and each absence degrades it.

As humans are complex agents which hold multiple goals at different scales, some of which may be conflicting or mutually exclusive, and whose priorities may change significantly and often over time, managing goals is a necessity. Accordingly, *managing goals* represents both the construction of sequences of actions meant to bring about individual goals, as well as the balancing and prioritization of multiple goals. Extending the example of a street map, sufficiently sophisticated computerized maps may automate the drudgery of detailed route-planning by simply performing that action, and may even allow for rapid trade-offs of related plans. Which alternative route is fastest? Which route requires least distance travelled? In a more complex setting, such devices may be aware of fluid or unrelated user goals, and pro-actively provide suggestions and alternatives. In the example of navigating an unfamiliar city, such an application might, given a particular place as a required destination, and mailing a postcard as a required goal without a specific location, provide lists of post offices and hours of operation near that location.

Finally, *acting* represents the (attempt at) modification of the environment by the agent. In human beings, this is limited to modifications of the position of the body, in reaction to which (the agent believes) the rest of the environment will respond: flexing the fingers and drawing back the arm just so will move an object from here to there; done with sufficient speed, the object may continue to move; movement of lungs, mouth, and vocal tract produces sound, to which other agents may react, etc. Many devices exist which increase the power, effectiveness or precision of an action, or even add actions not typically associated with human beings. However, in the context of our agency-extending urban navigation example, we may consider vehicles, which increase our hypothetical vacationer's rate of travel and ability to carry packages.

In each stage of this extended example, a human agent uses tools to increase performance of one of the four basic agent processes. In each case, the human's agency, or ability to act *effectively*, is enhanced in turn, although we recognize that the simplicity of the discussion stems from the illustrative assumption that these technologies do, in fact, "just work" as described. In the sensing process, our human agent has increased the performance of his or her vision by increasing its range; and/or used a tactile channel to "add" a literal sense of direction where none had existed previously, thus increasing the performance of his or her sensory system overall. These abilities interact directly with the subsequent phases of the agency loop. Being able to read street signs at a distance or know true north with precision makes it easier to build a mental model of the environment, makes planning easier, and may reduce extended information-gathering actions.[47]

Similarly, having an accurate map of any sort, paper or electronic, increases the agent's understanding of his or her environment, thus again resulting in fewer necessary observations to build a mental model (and as before, fewer actions in support of information gathering) and simpler planning and goal management. Should the mapping device be electronic and pro-active, it may simply perform many aspects of planning and goal management for the user. Modern GPS-enabled maps make navigation possible with almost no recourse to observation other than accident avoidance and the monitoring of the device itself, and almost no static understanding of the environment (although a dynamic understanding of traffic rules is still necessary). Finally, the possession of a vehicle which increases the agent's capacity to act can drastically reduce the time spent acting.

Establishing a common thread, this scenario highlights how tools may increase the ability of an agent to perform one or more of the processes associated with the agent loop of sensing, understanding, managing goals, and acting. This reduces the time spent either in the stage of the loop in question, or in other stages of the loop, or both. The end result is a more effective cycling through the loop, or the ability to act more effectively, relative to the goals of the agent. This is precisely an increase in agency as we define it.

All tools assist in the processes of the agent loop in some fashion or another, therefore all tools increase agency as we have defined it. However, not all tools are Human Augmentics. The gap lies in the difference between agency, and sense of agency.

Agency and Sense of Agency

Whereas agency, as defined in the previous section, relates to being able to act more effectively in relation to an agent's goals, a human's *sense of agency* derives from interaction with devices used to achieve goals. By increasing our sense of agency, Human Augmentics expands our potential agency. What sets Human Augmentics apart as a unique category of technology is the degree to which it could increase a human's sense of agency. A human's sense of agency increases

[47] Information gathering is typically a sensing process, but the limited range of human vision may require certain actions, such as walking closer to a street sign, prior to an *effective* sensing process.

when no device at his or her command imposes a mismatch between intent and allowable actions, or an undue burden on understanding the state of the tool.[48] By being attached to the body (directly, as in the case of wearables, or indirectly, as in the case of sensors) and environment in increasingly seamless ways, Human Augmentics devices integrate human-machine communication to bridge the gulfs between human, machine and environment.

The notion of agency is important for those working in the area of Human-Computer Interaction (HCI) as one central aim is to facilitate design of interactions that seem effortless; the popular Apple slogan, "it just works," sums up the HCI philosophy and the assumed expectation of users. But every time a device does not work as we anticipate it should, it decreases our sense of agency. Hannah Limerick, James Moore, and David Coyle define a sense of agency as "the experience of controlling one's own actions and, through this control, affecting the external world."[49] Sense of agency from this perspective assumes a mostly cognitivist model of the world that locates our sense of agency as derived internally. Offering a more substantial view of interaction, Don Norman, following from James Gibson,[50] defines a sense of agency according to an ecological perspective, taking into account that this sense of agency is entangled in a complex web that includes humans, devices, actions, and the environment.[51] Taking an ecological perspective helps account for a sense of agency as being co-constructed between a person, the devices at the person's disposal, and the environments in which they are embedded. In other words, to borrow from Deborah Lupton, it accounts for a "relational assemblage"[52] that is vital to understanding emerging configurations of human-machine communication.

According to Norman, actions involve both execution and evaluation.[53] The gulfs that result from a thing not responding in the way a user anticipates and

[48] Don Norman, T*he design of everyday things* (Revised and expanded edition.) (New York: Basic Books, 2013).

[49] Hannah Limerick, James W. Moore, and David Coyle, "Empirical Evidence for a Diminished Sense of Agency in Speech Interfaces" (ACM Press, 2015): 3967.

[50] James Jerome Gibson, *The senses considered as perceptual systems* (London: Allen & Unwin, 1968).

[51] Paul Dourish, *Where the action is: the foundations of embodied interaction (*Cambridge, Mass.: MIT Press, 2001).

[52] Deborah Lupton, "Digital Bodies" pre-print of a chapter published in Routledge Handbook of Physical Cultural Studies, edited by D. Andrews, M.Silk, and H. Thorpe, London: Routledge, (2016). Available online at http://www.academia.edu/14501199/Digital_Bodies. Last accessed April 30th, 2016.

[53] Note that in Norman's parlance, "execution" corresponds roughly to goal forming and acting in our previous defined agent loop, while "evaluation" corresponds roughly to

not giving the user information to change their actions to use it successfully are referred to as the gulf of execution and gulf of evaluation, respectively.[54] The gulf of execution speaks to a mismatch, or a barrier, between a set of desired actions and a set of allowable actions. In HCI, a large gulf of execution leads to interface designs that are artificial-seeming, intricate, fussy, and lead to a sense that the human is serving the machine rather than the other way around. Conversely, a small gulf helps ensure that the human feels in command of the device.

The gulf of evaluation "reflects the amount of effort that the person must make to interpret the physical state of the device and determine how well the expectations and intentions have been met."[55] The gulf of evaluation accounts for the mismatch between human understanding of the system and the underlying reality of the system. In HCI, systems with a large gulf of evaluation lead to users with large uncertainties as to the effects of their actions, and correspondingly high error rates, which again directly increases the sense that the user is employing a tool, and a badly designed one at that. The gulf is small when the device provides information about its state in a form that is easy to get, is easy to interpret, and matches the way the person thinks about the system."[56]

Bridging the gulf of evaluation is achieved through feedback and aligned conceptual models. While Norman is focused on how designers can use his models and concepts to help fill the gulfs, our contention is that Human Augmentics fill the gulfs of execution and evaluation in a dynamic way that could not only increase a human's sense of agency but also expand it. By incorporating miniaturization, advanced computing, sensory technology, and integrated textiles, Human Augmentics technologies attempt to close the gulfs of execution and evaluation. In doing so, they function below the level of conscious awareness as "calm technologies," matching actions with intentions "without being overwhelming or distracting."[57] Instead of extensions, these technologies are meant to collaborate with the human through seamless integration with the user and the environment. Their imagined functioning is so user-adaptive, properly anticipatory, and environmentally aware, they all but eradicate the gulfs which bring technologies into the full awareness of human interlocutors.

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sensing and understanding. Further, in Norman's conception, and in HCI in general, there is a particular emphasis on evaluating and acting on tools.

[54] Don Norman, *The design of everyday things* (Revised and expanded edition.) (New York: Basic Books, 2013), 39.

[55] Norman, *The design of everyday things*, 39.

[56] Norman, *The design of everyday things*, 39.

[57] Anne Galloway, "Intimations of Everyday Life: Ubiquitous computing and the city," *Cultural Studies* 18(2-3) (2010): 388.

In addition to helping close the gulfs, establishing a link between intentions and affordances, which account for the ecological nature of perceptual systems, helps explain how Human Augmentics could increase and expand a human's sense of agency. In establishing his anti-representationalist theory of perception, James Gibson develops the notion of affordances to explain the action possibilities supported by an environment.[58] His conception indicates that affordances are both intrinsic to the environment while also being a relational property. Don Norman imports his notion of affordances into HCI[59] by using it to help explain how designs succeed and fail to be user friendly, which in this case indicates an increase or decrease in the sense of agency.[60] The affordances of a technology, well designed, help align user intents with the allowable actions of the technology. In William Graver's terms, a technology that provides perceptual information about its affordances results in a "perceptible affordance," making explicit the allowable actions of a technology[61]. Instead of the intents informing the allowable actions, the affordances of technologies and environments often guide the intents of humans. The perceptible affordance of the technology prompts the human to adapt their intentions to fit the limitations of the technology. Even though well designed, the human is still operating under the constraints of the technology. Unable to adapt to the affordances of human interlocutors, devices given the moniker "smart," are actually anything but.

Human Augmentics, however, could potentially expand the possible intentions of humans through turning, what William Graver refers to as "hidden

[58] James J. Gibson, "The theory of affordances," in *Perceiving, Acting and Knowing*: *Toward an Ecological Psychology,* ed. Robert Shaw and John Bransford, (Hinsdale, NJ: Lawrence Erlbaum, 1977).

[59] It should be noted that Norman's notion of affordances breaks from Gibson, in that it relies more on an individual's cognitive ability than suggesting indelible qualities of the environment as Gibson intended. According to Victor Kaptelinin's entry into the 2nd edition of the Encyclopedia of Human-Computer Interaction affordances, https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/affordances, Norman's use of the term was highly influential in HCI but his lack of concise development of the concept created ambiguities of use in the field which Norman attempted to address in his 1999 publication in, In Interactions, "Affordances, Conventions, and Design."

[60] Don Norman, T*he design of everyday things* (Revised and expanded edition.) (New York: Basic Books, 2013); James Gibson, *The senses considered as perceptual systems* (London: Allen & Unwin, 1968).

[61] William Graver, "Technology Affordances," In proceedings of the ACM CHI 91 Human Factors in Computing Systems Conference, ed. Scott P. Robertson, et al. April 28 - June 5, 1991 (New Orleans, Louisiana): 80.

affordances" into "perceptible affordances,"[62] or what Don Norman refers to as "perceived affordances."[63] By being able to sense data about the world that could be imperceptible to humans, including embodied information unknown to the human interlocutor, these devices could reveal affordances in our environments and technologies that would otherwise be hidden, allowing the human to expand their world of potential actions and their sense of agency along with it.

Our contention is that just as non-augmentic technologies (i.e., tools) can increase and expand our agency by allowing us to better sense, understand, and act on the world, Human Augmentics could increase and expand our *sense of agency* by providing information about ourselves, our environments, and our tools, persistently augmenting our senses in ways that were hitherto impossible, *as well as* by reacting to or anticipating our intentions as smoothly as our own bodies. Instead of blending with the human to mediate as "functional organs,"[64] or to alter our body schema[65], both of which rely on reshaping the human to achieve the actions of the machine, Human Augmentics are meant to bend to human intention. By being more adaptable to the individual and the environment, Human Augmentics can in principle correct for "problems with interactive technology (that) lay in the imbalance between situated organization of practical action and the regimented models that systems embody."[66] The devices operate more flexibly and dynamically, matching human intention, but more fundamentally, the devices more adequately close the gulfs of execution and evaluation, creating feedback mechanisms that actively account for, and adapt to, users, devices, and environments.

This formulation, that a technology might be considered Human Augmentic if it both expands the user's agency and sense of agency simultaneously is aspirational as well as definitional, serving as a roadmap for discourse and development. Our previous extended example of the agency loop, for instance, made the simplifying assumption that the technologies in question simply worked, properly and reliably. However, any user of GPS navigation

[62] Graver, "Technology Affordances": 80.

[63] Don Norman, "Affordances, Conventions, and Design," *In Interaction* 6 (3): 38.

[64] Victor Kaptelinin and Bonnie A. Nardi, *Acting with Technology: Activity Theory and Interaction Design* (1st paperback ed.) (Cambridge: The MIT Press, 2009), 249.

[65] Nina B. Dohn, "Affordances Revisited: Articulating a Merleau-Pontian view," In *International Journal of Computer-Supported Collaborative Learning*, 4(2), 2009: 151 - 170.

[66] Paul Dourish, *Where the action is: the foundations of embodied interaction.* (Cambridge, Mass.: MIT Press, 2001), 122, summarizing an argument Lucy Suchman makes in her first edition of *Plans and Situated Actions: The Problem of Human-Machine Communication* (Cambridge: Cambridge University Press, 1987).

applications who has found him or herself miles from their destination due to poor directions knows that this is not so. Any similar assumption of technologies which increase a user's sense of agency must be treated with similar skepticism, for reasons ranging from the technical difficulty of implementing such features and their associated failure modes, to the difficulty of truly untangling and/or measuring a sense of agency, to broader questions of human agency confounded by social, cultural, and historical forces. Two brief examples serve to illustrate these broader questions, before moving on to extended cases studies that expand on these points.

First, consider existing therapeutic devices such as (highly experimental) wheelchairs controlled by brain-computer interfaces. Such interfaces function by making direct or indirect measurements of brain activity, interpreting them, and converting them into machine instructions. This technology, as described, may simply fail, producing no action or some action contrary to the user intent, thus confounding user agency, user sense of agency, or both. However, consider a more advanced version of this technology, coupled to video cameras supplementing the brain measurements with contextual information from the environment, e.g., for collision avoidance or for smooth alignment of the vehicle as it passes through a narrow portal. (Derry and Argall describe a similar system, although fusing a more conventional therapeutic interface with environmental context[67].) Such devices may fail in increasingly sophisticated and problematic ways, such as smoothly aligning the vehicle for passage through the wrong door. When extended from the therapeutic to Human Augmentics domain, these problematic scenarios highlight the critical need to think carefully through such questions of agency, intent, and sense of agency.

Second, consider the case of a device which assists a user in managing goals. Such a use-case falls logically from our definition of agency as acting *effectively* with intent, and from our definition of the agent loop. But while some use cases may be benign (for instance, the case of route planning with multiple destinations) other, more captological approaches pose difficulties. A fitness and diet mobile computer application may be seen as an act of externally mediated self-persuasion, or, depending on its construction and authorship, may be seen as a sophisticated advertising campaign on the part of the application designers. Again, careful analyses are necessary, even in the case of robust technological implementations, to distinguish mere tools, from deceptive or constraining agency-reducing devices, from Human Augmentic technologies.

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[67] Matthew Derry and Argall Brenna, "Automated doorway detection for assistive shared-control wheelchairs," *Robotics and Automation (ICRA), 2013 IEEE International Conference on*. IEEE, 2013.

Human Augmentics Scenarios

Three technologies, SpiderSense, BLEEX and LiveNet, serve as concrete examples that illustrate how Human Augmentics technologies may increase both a user's agency and sense of agency, making them more aware of their surroundings and allowing them to make more informed decisions or enhancing their actions. These devices act as agents themselves, sensing the environment (including the user) using sensors, understand and manage goals using their processing capabilities, and act by using HCI methodologies to communicate with the user or act on the user's behalf. However, all three also provide examples of how failure to function as Human Augmentic threatens human agency in ways that demands critical attention.

SpiderSense

SpiderSense[68] is a wearable suit that allows the wearer to feel the environment on his or her skin. SpiderSense consists of thirteen ultrasonic rangefinders that detect obstacles, an Arduino for processing that information, and thirteen servo motors to provide haptic feedback. Drawing on our definition of Human Augmentics, SpiderSense's intent is to increase the user's agency and sense of agency by making them more aware of their surroundings. However, due to the sensors' limitations and missing contextual information, it might not always succeed in its purpose, as we will see in the preliminary experiments. The device itself adheres to the agent loop, as it senses the environment through the ultrasonic rangefinders; understands the environment through processing and filtering the raw signals from the sensors; and acts by nudging the wearer through the servo motor. The device's loop of agency is intertwined with the human's, as the user's understanding of the environment depends on the current and past feedback of the device, their plan depends on the understanding from the previous step, and their selected action depends on the plan. While SpiderSense does not have a memory (the model of the environment in the "understand" step depends on only the current sensor readings) it does react based on the human's selected plan, i.e., it is a reflex agent. For example, after an obstacle has been detected and the user has been informed through the use of pressure to their skin, if the user continues to

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[68] Victor Mateevitsi, Brad Haggadone, Jason Leigh, Brian Kunzer, and Robert V. Kenyon, "Sensing the Environment Through SpiderSense," in *Proceedings of the 4th Augmented Human International Conference*, AH '13 (New York, NY, USA: ACM, 2013).

move towards that object the pressure will increase. Furthermore because of SpiderSense's haptic feedback, the human's sense of agency increases, as there is (ideally) no mismatch between intent and allowable actions.

During preliminary experiments, participants were able to navigate hallways and detect pedestrians while walking blindfolded outdoors. In another experiment, participants were able to detect people that were walking around them, report their position by pointing, and accurately throw styrofoam stars at them. The device was tested primarily on blindfolded individuals with some early secondary feedback from people with visual disabilities. Participants in general were able to navigate, detect obstacles and people, and were very positive about the technology and its potential. The visually impaired participants in particular asked for a more portable device without tethered cables that would be easier to wear. All participants reported that they were able to immediately use the device and that the pressure feedback was easily understood; people wearing the device for the first time, without any prior training or instructions were able to navigate simple courses and perform a pointing task (where a user walks around the participant wearing the device).

In the paper the authors also describe an experiment, performed in the library of their university, that confused participants instead of increasing their agency and sense of agency. In this experiment, subjects had to walk pre-described paths between bookshelves without touching them. During the experiments, subjects were unable to distinguish an opening from an empty book shelf, therefore feeling confused. This scenario is a good example of Human Augmentics technologies that fail to address all environments and use cases, as they are restricted by their sensors' limitations, computing power, lack of contextual information, etc. Researchers, engineers and designers need to be cautious when claiming that a technology is Human Augmentics and address when and why a the device might not work as expected.

For sports and other physical activities, feedback about body posture, movement, positioning, etc., are essential for skill development and improvement. Traditionally, athletes have trained under the supervision of a personal trainer or a coach, who would give them feedback based on their experience, knowledge, and external perspective, or they may have viewed photos or videos of their performance. However, even experienced coaches and athletes may not detect or see small micromovements that are incorrect. Human Augmentics devices can improve learning and motor skills by sensing, understanding and acting in real time. Devices like SpiderSense that use the skin to provide feedback are known in the literature as tactile displays. These devices can communicate messages through pressure, vibration[69], lateral skin deformation, temperature or electric stimulation. Studies have shown that tactile stimulation can be beneficial for learning and improving motor skills, such as dancing,[70] rowing,[71] karate,[72] archery[73] and snowboarding.[74] Preliminary user studies have also shown promise in maintaining a high performance level with elite athletes in soccer, cycling, and speed skating.[75] By sensing user movement and behavior, these devices understand the movement and goals of the user and act by providing feedback as to improve their learning and motor skills. As we described earlier, the devices act as agents that go through the agent loop, thereby increasing the user's agency and sense of agency. Another use of tactile displays is for orientation and mobility. Bach-y-Rita and Collins showed that using a 20x20 vibrotactile array that encoded a camera video feed to vibrotactile stimulation on the back of the patient, blind participants were able to recognize the position, size, shape, and orientation of visible objects as well as track moving targets.[76]

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[69] Carter Compton Collins, "Tactile Television - Mechanical and Electrical Image Projection," *IEEE Transactions on Man-Machine Systems* 11, no. 1 (March 1970); Paul Bach-Y-Rita et al., "Vision Substitution by Tactile Image Projection," *Nature* 221, no. 5184 (March 8, 1969).

[70] Akio Nakamura et al., "Multimodal Presentation Method for a Dance Training System," in *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '05 (New York, NY, USA: ACM, 2005).

[71] Jan B.F. van Erp, Ian Saturday, and Chris Jansen, "Application of Tactile Displays in Sports: Where To, How and When to Move," in *Proc. Eurohaptics*, 2006.

[72] Aaron Bloomfield and Norman I. Badler, "Virtual Training via Vibrotactile Arrays," *Presence: Teleoperators and Virtual Environments* 17, no. 2 (March 17, 2008).

[73] Heng Gu, "Exploring Sensory Augmentation Through Tactile Interfaces," in *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers*, UbiComp/ISWC'15 Adjunct (New York, NY, USA: ACM, 2015).

[74] Daniel Spelmezan, "An Investigation into the Use of Tactile Instructions in Snowboarding," in *Proceedings of the 14th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '12 (New York, NY, USA: ACM, 2012).

[75] Jan B.F. van Erp, Ian Saturday, and Chris Jansen, "Application of Tactile Displays in Sports: Where To, How and When to Move," in *Proc. Eurohaptics*, 2006.

[76] Paul Bach-Y-Rita et al., "Vision Substitution by Tactile Image Projection," *Nature* 221, no. 5184 (March 8, 1969); Carter Compton Collins, "Tactile Television - Mechanical and Electrical Image Projection," IEEE Transactions on Man-Machine Systems 11, no. 1 (March 1970); For a more thorough survey see: Vasilios G. Chouvardas, Amalia N. Miliou, and Miltiadis K. Hatalis, "Tactile Display

The Berkeley Lower Extremity Exoskeleton (BLEEX)

Even though human strength and endurance is constrained by our bodies' physical limitations, Human Augmentics technologies may allow us to overcome these limitations. Exoskeletons are still in development, technologies that aim to allow us to walk further, and carry heavier payloads without getting tired. By augmenting our bodies with an exoskeleton, we can perform tasks more easily and safely, without putting our bodies to danger. BLEEX is a lower extremity exoskeleton with seven degrees of freedom per leg, four of which are powered by linear hydraulic actuators.[77] In contrast with previous exoskeletons such as HAL,[78] BLEEX is capable of carrying a payload in addition to its own weight. Participants wearing BLEEX can carry a payload of up to 75 kg, walking at speeds exceeding 4.5 km/hr. BLEEX increases human carrying capacity and endurance in rough and uneven terrains that are inaccessible by vehicles. BLEEX senses the operator's movements through a set of sensors, understands the movement of the operator through a control algorithm that has been trained using Clinical Gait Analysis (CGA) and acts by moving the linear actuators and thus providing enhanced strength and endurance. BLEEX fits well into our proposed Human Augmentics model. Following the agent's loop, it senses the user's body posture and movement, understands the user's intention and acts by synchronizing the movement of the exoskeleton legs with the user's legs thus allowing them to carry the payload. BLEEX increases the user's agency, by enhancing their strength and endurance, and the user's sense of agency by allowing them to act and manage goals—that otherwise would not be possible—without the machine getting in their way. However, as with any technology in its infancy, there are some limitations as the device's kinematics and dynamics do not fully match the human's, imposing a mismatch between intent and allowable actions and therefore decreasing the user's sense of agency. Human Augmentics technologies that overcome the body's physical limitations, like strength and endurance, need to be carefully designed, tested and made explicit as a malfunction or wrong movement can lead to serious injuries.

Applications: A State of the Art Survey," in *Proceedings of the 2nd Balkan Conference in Informatics*, 2005.

[77] Adam B. Zoss, Hami Kazerooni, and Andrew Chu, "Biomechanical Design of the Berkeley Lower Extremity Exoskeleton (BLEEX)," *IEEE/ASME Transactions on Mechatronics* 11, no. 2 (April 2006).

[78] Hiroaki Kawamoto and Yoshiyuki Sankai, "Power Assist System HAL-3 for Gait Disorder Person," in *Computers Helping People with Special Needs*, ed. Klaus Miesenberger, Joachim Klaus, and Wolfgang Zagler, Lecture Notes in Computer Science 2398 (Springer Berlin Heidelberg, 2002).

LiveNet

Proactive monitoring of patients can reduce healthcare costs and detect early signs of health problems. LiveNet[79] is a wearable platform for long-term health monitoring and patient feedback that aims to improve quality of life and delay the onset of medical conditions. It measures body vitals and senses the context using specialized sensors, understands the sensor data and analyzes patterns in data collected from all LiveNet users, and acts by providing real-time results to the user. What sets LiveNet apart from SpiderSense and BLEEX is its use of data collected from all users to create statistical machine learning models that are then used to classify and distinguish between different states. For instance, the system was able to distinguish with 95% accuracy shivering from general body movements in various activities, nearly 100% accuracy in predicting when a patient will experience dyskinesia (a symptom of Parkinson's disease) and with 84% accuracy in classifying between 20 daily activities (such as vacuuming, eating, folding laundry, etc.). Human Augmentics devices that use the cloud and machine or deep learning techniques can have the advantage of learning from the general population when something happens and therefore being able to identify small patterns or anomalies that otherwise would be unnoticeable. By using this knowledge they can predict what will happen next or can distinguish between a correct and incorrect form and can act by intervening in real-time to increase our sense of agency. But as with the previous examples, the system is not 100% accurate: while 84% accuracy is a great statistical result, there is still a 16% chance that the device will falsely recognize an activity or condition, affecting the human's model of the world or their goal management. Ramifications of such an event could be minimal, from recognizing a wrong activity and having an incorrect calorie calculations, to very serious ones, like taking a drug when they shouldn't or having negative psychological effects. As is the case with most all extrapolations from the aggregate to the individual the consequences require forethought and the desires behind them require critique.

Conclusion

These examples illustrate some of the ways that Human Augmentics can be operationalized via devices that increase a person's agency as well as sense of agency. They as clearly illustrate that the engagement of human and machine they

[79] Michael Sung, Carl Marci, and Alex Pentland, "Wearable Feedback Systems for Rehabilitation," *Journal of NeuroEngineering and Rehabilitation* 2 (2005).

incorporate requires critical analysis lest Human Augmentics becomes another ambiguous (though nevertheless heuristic) totem, like Marshall McLuhan's notion of "extensions of man"[80] or Andreas Hassan's "computer as substitute consciousness,"[81] or, worse, that it becomes another utopian expression of an uncritical symbiosis of human and machine. We wish therefore to emphasize that Human Augmentics devices are implicated and embedded in the dynamic practices of design, use and and understanding of self and environment, and ought not be merely conveyors of information about the environment or user, and instead could be actively engaged in processing and communicating information about the user and environment. Human Augmentics devices operate in the verge between body and machine, wherein sensing of the environment and the body are the fulcrum, and Human-Machine Communication is the lever. By dynamically mapping, in real time, what had hitherto been unmappable (synchronously and/or invisible to the senses) Human Augmentics at once recedes as a technology and grows as an interlocutor. As James Carey reminds us any act of mapping is "a reduction of information… that bring(s) the same environment alive in different ways."[82] Human Augmentics devices do not merely represent reality but act collaboratively with the user in its construction.

There are two (related) consequences of this collaboration, one specific to design and Human-Computer Interaction (HCI), the other general in regard to the intersection of technology and power. As we noted earlier in our essay Human Augmentics devices all but eradicate the gulfs which bring technologies into the full awareness of users. However, such a paradigm "intentionally hid[es] the phenomena and materiality of interfaces," and "smooth[s] over the natural edges, seams and transitions that constitutes all technical systems, [and] entails a loss of understanding and agency for both designers and users."[83] In the case of design for Human Augmentics devices it is necessary not only to undertake device testing and user testing but also to evaluate in place and in context. Special emphasis should be given during design and testing, as well as during ongoing evaluation in use, on testing cognitive load, sensory competition, agency and sense of agency.

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[80] Marshall McLuhan, *Understanding Media: The Extensions of Man* (Cambridge, MA: MIT Press, 1994).

[81] Andreas Huyssen, A., "Mapping the Postmodern," *New German Critique 33* (1984), 5-52.

[82] James W. Carey, *Communication as Culture: Essays on Media and Society* (New York: Routledge, 1992), 28.

[83] Timo Arnall, "No to NoUI." (March 13 2013.) Retrieved online: http://www.elasticspace.com/2013/03/no-to-no-ui. Last accessed April 25th, 2016.

Emphasis on cognition and agency will also be required in future research. Whereas Human Augmentics relies on a reconciliation of and collaboration between human and machine it is necessary to understand the simultaneous, multiple, contingent elements comprising agency and behavior. In the view of those espousing enactivism[84] the importance of intersubjectivity not only between humans and between humans and agents but also between agents is important in understanding the dynamics of interaction.[85] As Torrance & Froese[86] noted based on constructing experimental models with simple artificial agents, in response to the emergence of participatory sense-making, "the inter-individual interaction process, *taken as a whole system*, can have important properties that in principle can neither be *separated* from the being and doing of the interacting individuals, nor be *reduced* to the being and doing of those individuals alone."[87] The paradox, and challenge to HCI, is that while Human Augmentics devices increase agency and sense of agency they also rely on placing increasing trust in agents while simultaneously making the agents less visible, obscuring opportunities for "reflexivity in technical practice" of the kind called for by Steven Harrison, Phoebe Sengers, and Deborah Tatar.[88]

By closing the gulfs we may eradicate the "seams and scars" in current interfaces that create "places where interventions can be made, or where potential can be acted upon."[89] One consequence, for example, might be that by increasing performance in an agent loop we may experience a loss of serendipity. A map that works too well could create a path dependency that would not allow us to stray, get lost, discover something new. But Human Augmentics devices may also create new spaces for intervention. The maps Human Augmentics devices, like all technologies, produce are symbolic realities, ones with which and over which users struggle. They require continual communication, interpretation and

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[84] Francisco J. Varela, Eleanor Rosch and Evan Thompson, *The Embodied Mind: Cognitivie Science and Human Experience*. (Cambridge, MA: MIT Press).

[85] Hanne De Jaegher and Ezequiel Di Paolo, "Participatory Sense-Making: An Enactive Approach to Social Cognition," *Phenomenology and the Cognitive Sciences 6* (2007), 485-507.

[86] Steve Torrance and Tom Froese, "An Inter-Enactive Approach to Agency: Participatory Sense-Making, Dynamics, and Sociality," *Humana.Mente* 15 (2011), 21-53.

[87] Torrance and Froese, 38.

[88] Steven Harrison, Phoebe Sengers and Deborah Tatar, "Making Epistemological Trouble: Third-Paradigm HCI as Successor Science," *Interacting With Computers* 23 (2011): 385-392.

[89] Anne Galloway, "Seams and Scars, or How to Locate Accountability in Collaborative Work" In *Uncommon Ground*, ed. Cathy Brickwood, Bronac Ferran, David Garcia and Tim Putnam. (Amsterdam: BIS Publishers, 2007), 152-58.

understanding. Unlike communication technologies with which we already have experience, and unlike other types of wearables or fitness trackers, Human Augmentics devices do not merely mediate or provide data, they collaborate. By adapting to the intentions of the human rather than requiring humans to adapt to the intentions of the technology, Human Augmentics alters sense of agency. It does this by transducing affordances from technology to the information generated, stored, and exchanged through the human-machine assemblage.

Human Augmentics devices collect information about the environment and people imperceptible to humans and then relay that information in ways that expand a human's sense for potential actions. The information proper becomes the affordance rather than the technology itself and provides opportunities for enaction, of "technology beyond that of tools, reaching as far as ubiquitous accompaniment of sense-making."[90] The information generated by sensing the body and the environment in ways directly unavailable to the human perceptual system creates a layer of information about the body and the environment that affords the potential for controlling the body and environment in new ways. Likewise, the information becomes an affordance for the devices, informing it how to adapt to the user. Thus, a person's sense of agency is not merely increased by communication with the device, but expanded and enacted through the information affordances generated in the verge the devices paradoxically obscure.

Human Augmentics is thereby about bending instead of blending. While the vision of ubiquitous and mobile computing that is seamless may invoke notions of cyborgification, the idea is not that technologies will merge with humans, subsuming them with, or into, the machine, rather that by altering forms of communication, devices more properly bend to the will of human users, reinforcing and expanding potential agency. The point of Human Augmentics is to develop communication between the human, machine, and environment premised on collaboration rather than co-option, engagement rather than estrangement, to increase human agency and a human's sense of agency, not to eradicate the human in pursuit of becoming something other. Human Augmentics, then, is focused on the intersections between human and machine, about the information that is generated between agents, and the affordances that information provides to potentially increase agency.

[90] Mauri Kaipianen, Niklas Ravaja, Pia Tikka, Rasmus Vuori, Roberto Pugliese, Marco Rapino and Tapio Takala, "Enactive Systems and Enactive Media: Embodied Human Machine Coupling Beyond Interfaces," *Leonardo* 44(5) (2011): 433-438.

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