RESEARCH-ARTICLE

Three Perspectives on Human Vulnerability: Enriching Responsible Computing Design Processes1

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Three Perspectives on Human Vulnerability: Enriching Responsible Computing Design Processes[1]

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In response to the increasing interest in (designing for) human vulnerability within the field of responsible computing, we articulate the multi-dimensionality of the concept of vulnerability to deepen and enrich the conversations about the relationship between vulnerabilities and the design of assistive technologies. Drawing on different philosophical traditions and insights from critical disability studies, we introduce three perspectives on vulnerability–the *individualist, relationalist*, and *enactivist* perspectives–that each emphasize a different aspect of what it means to be vulnerable. We argue that, for engineers in the field of responsible computing, it is key to be able to adopt all three perspectives and explicitly and critically reflect upon what

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each perspective or combination of perspectives brings to the design context at hand. When used in conjunction, the three perspectives together can mitigate the risk of creating technological interventions that may aim at ameliorating vulnerabilities but instead exacerbate or create new ones. To move forward, we call for further reflections and practical considerations on how to best integrate the three perspectives on vulnerability into participatory design practices; how to distribute responsibilities within design teams to ensure that all perspectives are genuinely adopted and engaged with; and how to foster creative, out-of- the- box thinking for assistive technology design.

CCS Concepts: • **Human-centered computing → HCI theory, concepts and models; • Applied computing → Arts and humanities**;

Additional Key Words and Phrases: Computing for vulnerability, assistive technology, philosophy of technology

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1 Introduction

Digital technologies are becoming intimately interwoven with people's daily lives [Van de Poel et al. 2022; Van Est et al. 2014]. As these technologies are transforming and reconfiguring cognitive, affective, bodily and conative capacities, the field of computing shows a growing interest in how this entanglement of human life with digital technology requires analyses that foreground human *vulnerability*. For instance, Greenberg and Marble [2023] argue for the essential importance of accounting for vulnerability in what they refer to as "Person-Machine Teaming". Relatedly, Tschopp [2020] argues in favor of putting vulnerability at center stage in the context of trustworthy AI and human-machine interaction. Furthermore, Van Riemsdijk [2018] proposes that "Intimate Computing" is best understood as "Computing with Vulnerability", aiming at realizing Intimate Technologies that empower and support people in engaging with and reflecting on their (technology-mediated) personal vulnerabilities throughout their day. We see additional pleas for a vulnerability-focused understanding of our digitally-mediated lives in Malgieri [2023] and Ranchordas [2021].

As philosophers and HCI researchers who consider vulnerability to be an important concept for understanding the disruptive effects of emerging (digital) technologies on the human condition, we welcome this growing emphasis on vulnerability in the field of computing.[2] However, we also observe that while the connection between human vulnerability and digital technology is receiving increasing attention, a broad recognition of its importance for Responsible Computing is still lacking. Furthermore, though most people have intuitions about what vulnerability entails–e.g., being exposed to risks of experiencing harm or injustice, experiencing an undesirable degree of destabilizing dependency and an increased need for care–the concept has received little systematic attention in Responsible Computing scholarship and is rarely analyzed in depth.

Etymologically, vulnerability refers to the ability to be wounded or harmed. The desire to mitigate vulnerability–understood as *harm-ability*–is a pervasive driver of technological innovation even when it is not thematized as such. From airbags to ambient assisted living technologies, and

[2]In this context, see also Babushkina and Votsis who argue that the intimate pairing between human selves and machines, particularly AI, generates new forms of disruption that "can easily turn into human harm when the frameworks facilitating it overlook the human vulnerabilities that arise from hybrid identity." (2022, 611).

from security systems to CPR machines, many of the artifacts that engineers design are a direct response to the desire to mitigate human harm-ability. One of the underlying concerns of our article is that it matters a great deal how such mitigation is pursued, which, in turn, depends on how exactly vulnerability is conceptualized.

Presently, as we will detail, there is a tendency to take an *individualist perspective on vulnerability* (see Section 2.1) and to pay insufficient attention to scholarship that foregrounds the relational character of vulnerability. This scholarship, found in areas such as feminist philosophy, critical disability studies, and philosophy of technology, emphasizes that an answer to the question of what it means to be vulnerable must consider not only aspects of the individual human being (e.g., cognitive decline or physical frailty) but also the aspects of the social and material environment in which humans are situated. We call this *a relational perspective on vulnerability* (see Section 2.2). As embodied and social beings, humans are deeply entangled with and dependent on their environment in a variety of specific ways. drawing on insights from enactive embodied cognitive science (*enactivism* henceforth),[3] we argue that this entanglement not only exposes human beings to a variety of possible harms but also facilitates processes of meaning-making. This, we show, points to a third, *enactivist*, perspective on vulnerability: *vulnerability as entangled with meaning-making* (Section 2.3) .

In this article, we seek to lay the foundations for a more systematic and explicit engagement with these three perspectives on vulnerability in the field of computing. We consider this a worthwhile endeavor because how vulnerability is conceptualized can have a direct bearing on how it is operationalized in computing projects. Although we take our approach to have broad applicability, we show the relevance of considering vulnerability from three different perspectives by looking at computing initiatives in the space of assistive technology,[4] as this is an area in which vulnerability is emphatically at stake. Using two recurring examples of assistive technologies intended to support the lives of people with (1) mobile and (2) communication-related disabilities, we bring into view the value of oscillating between the three perspectives on vulnerability articulated here. Ultimately, we propose that this oscillating posture can contribute to more respectful and creative design processes and technologies that better reflect the multivarious ways in which vulnerability can manifest and texture a person's life.

The article is structured as follows. In Section 2, we introduce the different perspectives on vulnerability and discuss each perspective's appeal and potential downsides. Subsequently, in Section 3, we advocate for developing critical reflexive participatory design processes in which each of these perspectives is represented or at least taken into account. We discuss the work by Zaga et al. [2022] and Williams et al. [2022] as exemplary works of reflexive participatory design with vulnerability in mind. Finally, in Section 4, we identify remaining open questions and call for the field of responsible computing to engage with, and further contribute to, an enriched understanding of vulnerability.

[3]The enactive strand in cognitive science argues that the ability of living beings to respond intelligently to their environment (or to make sense of their environment) is enabled by the specific way in which a living being is and has a body. Enacting a world constitutively requires embodiment, which signifies more than the obvious fact that living beings, including human beings, have physical bodies, without which they would not be able to sense or move. Specifically, it refers to the unique characteristics of living bodies that make sense-making possible. Living beings are constantly preserving their *bounded autonomy* as a unified self-organizing system through ongoing adaptive exchanges with an environment to which they are *precariously exposed* and upon which they are fundamentally *dependent* [Thompson 2007; Di Paolo and Thompson 2014].

[4]Broadly put, assistive technologies refer to technologies specifically designed to support independence for disabled and chronically ill people–people who often experience heightened vulnerability across multiple areas (physical, economic, social). For a powerful documentary on the uneven distribution of vulnerability across multiple areas, see *When Billy Broke his Head*. For a historical tracing of the term "assistive technology" in legislation, see Edyburn [2004].

2 Vulnerability: Individualist, Relationalist, and Enactivist Perspectives

In what follows, we will articulate three different perspectives on vulnerability. These perspectives tend to highlight different aspects of what it means to be human, namely: (1) to function as an independent bodily and minded individual; (2) to be relationally shaped by and dependent on one's social and material environment; (3) to give active meaning to the environment in which one is embedded. Each perspective can animate different design approaches to human vulnerability. As indicated, we advocate for a critical awareness of these three perspectives by illustrating how they can translate into decidedly different approaches to the design of assistive technologies. As each perspective contains both truisms and pitfalls with respect to understanding and designing for human vulnerability, we advocate for an approach to computing for vulnerability that critically reflects on the relevance and legitimacy of each perspective within a given computing project.

As mentioned in the introduction, we illustrate the differences between the three perspectives by focusing on assistive technologies intended to support the lives of people with mobile and communication-related disabilities. Assistive technologies often aim at mitigating vulnerabilities in the lives of disabled people by intervening at the level of disabled people's individual body-minds. This places the source of vulnerability stemming from disability squarely and non-relationally on the side of the disabled individual who is seen in isolation from their relationship to their environment [see e.g., Lin et al. 2025; Kim et al. 2025; Erard 2017]. In such contexts, vulnerability is conceptualized primarily–perhaps even solely–in terms of deficient or lacking abilities that are to be restored via computing interventions. We identify this as the individualist posture toward vulnerability (Section 2.1). The problems with such an individualist, non-relational approach toward vulnerability have been widely documented in the fields of feminist ethics and critical disability studies, but, to the best of our knowledge, this has not yet been brought to bear on the growing interest in vulnerability within the field of computing. As we argue (Section 2.2), attending to this is of prime importance, because it can help circumvent the creation of what feminist philosophers Mackenzie, Rogers, and Dodds have termed *pathogenic vulnerabilities* [Mackenzie et al. 2013].

Pathogenic vulnerabilities are a specific type of vulnerability that are the product of a somewhat paradoxical situation, in which *efforts aimed at ameliorating vulnerabilities end up precisely exacerbating existing or creating additional vulnerabilities*. Think, for instance, of an assistive tracking device aimed at supporting independent living that, by exposing sensitive user data, actually renders a user more vulnerable than before. Likewise, consider a technology aimed at supporting mobility that is in fact designed in ways that heighten user stigmatization [Desmet and Roeser 2015]. Building upon insights from critical disability studies, feminist ethics, embodied cognitive science and philosophy of technology, we argue that the creation of such pathogenic vulnerabilities can, in some cases, be avoided by taking seriously the intertwinement of individual vulnerability, relationality, and meaning- making (Section 2.3). At the same time, as we will also discuss, the relationalist and the enactivist perspectives on vulnerability, when taken in isolation, can also come with their own limitations that could cause pathogenic vulnerabilities. We therefore advocate a critical awareness among engineers in responsible computing of these different approaches to vulnerability. We emphasize the importance of being able to oscillate between the three approaches and critically reflect upon what each perspective, or combination of perspectives, can bring to a design initiative and project aim. That said, we maintain that, in our current Western sociotechnical climate, there is a strong emphasis on individualistic approaches to vulnerability in the context of assistive technology, such that the pathogenic vulnerability pitfalls tethered to this perspective warrant special attention.

2.1 Vulnerability: An Individualist Perspective

There is a fairly prominent tendency in contexts of technological innovation to understand human bodily vulnerability by accepting (either implicitly or explicitly) the following two assumptions: (1) that vulnerability is inherently undesirable; and that (2) vulnerability is a phenomenon that lends itself to a perspective of methodological individualism. What we mean by the latter is the view that sources of vulnerability, e.g., illness, disability, or aging, can be identified and understood by locating them squarely and non-relationally on the side of the individual person whose bodily and minded functioning (and alleged deficiencies therein) are seen in isolation from the wider environment that a person inhabits [see e.g., Lorah et al. 2021, Wojtyna et al. 2023]. You see this very clearly in the medical model of disability, "according to which disability is nothing more than a kind of biological disorder" [Barnes 2016, 1]. On this view, disability warrants interventions at the level of the individual's disordered vulnerable state of being [Clare 2017]. As Ashley Shew points out, the "attitude that disability is always a negative and always an individual problem extends into our ideas about and designs for the ideal future" [2020, 41].

We see these assumptions operating in the background of a multitude of interventionist assistive technology projects that often use the language of "restoring" lost abilities.[5] To be sure, changes or losses in one's bodily functioning can be experienced as profoundly challenging and undesirable, exposing a person to experiences of heightened vulnerability. This, then, could warrant or justify a technological response. It is vital to be aware, though, that interventionist restoration efforts tend to focus narrowly on discrete elements of a person's body or mind as causing dysfunctioning. As *dys*functioning is understood in contrast with adequate functioning, non-disabled embodiment is typically implicitly taken as an exemplary normative baseline that informs interventionist ideas about what adequate "natural" functioning ought to look like and what it means for such functioning to be "restored". Much mainstream, everyday thinking, which is both reflected in and amplified by narratives surrounding assistive technology, runs like this; readily assuming, for example, that amputated limbs are to be replaced with bionic ones that approximate "natural" (read "normal") bodily appearance and functioning as closely as possible. A case in point is Hugh Herr's vision for developing cutting edge mobility disability tech at MIT's bionics lab, as reflected in the following MIT News press release:

> "Scientists and engineers are taking design cues from biology itself to create revolutionary technologies that *restore the function of bodies affected by injury, aging, or disease* — from prosthetic limbs that effortlessly navigate tricky terrain to digital nervous systems that move the body after a spinal cord injury" [Michalowski 2021, our italics].[6]

Similarly, in the space of assistive communication, the ambition can be observed to technologically bolster the allegedly deficient uncommunicative behaviors of non-speaking autistic children with technologies that are designed to "replace existing problem behaviors … [and] … promote new and desired behaviors;" technologies that equip users with "conventional acts that have equal or greater communicative power for the user" [Wilkinson and Reichle 2009, 355–6]. Certainly, such forms of assistive technology might be desirable, suitable, even pivotal, to circumvent a range of possible harms. For instance, access to a well-fitting and smoothly functioning prosthetic device might decrease one's susceptibility to harm as a mobile subject who needs to access a variety of terrains and infrastructures to navigate daily life. Similarly, assistive communication

[5] On this topic, see also Van Balen (Forthcoming) who identifies how this language of restoration operates in characterizations about the potential of brain-computer-interfaces used for communication.
[6] https://news.mit.edu/2021/new-bionics-center-established-mit-24-million-gift-0923

technologies that enables users to express sentences such as "This hurts," or "Stop, I don't like this," have played a significant role in mitigating their harm-ability, by decreasing their exposure to physical and sexual violence [See Beukelman and Mirenda, 2013].

That said, we want to warn against the idea that interventionist restoration efforts are unproblematic approaches to mitigating human vulnerability that should be pursued uncritically. Several of the limitations of this approach will become apparent in sections 2.2 and 2.3. For starters, we begin by critiquing the stigmatizing framing of users of assistive technology as deficient, needy, or passive,[7] and of technology as unproblematically pulling people out of the presumed deplorable vulnerable state that they are in. Such a view is reflected in Herr's vision for the future as his lab strives "toward a technological future in which disability is no longer a common life experience" [quoted in Michalowski, 2021]. This kind of outlook, which is widely rejected by disability rights activists [see e.g., Clare 2017; Hamraie and Fritsch 2019; Shew 2023; Schalk 2017; Minich 2017; Meekosha and Shuttleworth 2017; Goodley et al. 2017], is reflective of a quasi-transhumanist viewpoint, which aims at radically enhancing human nature through technological interventions in an effort to insulate people from the vulnerabilities that, without technological intervention, inevitably spring from our natural make-up.[8] By enhancing people's physical, sensorimotor, cognitive, volitional, and affective capacities, the transhumanist hope is that it is possible to inhabit a future in which the presumed malaise that comes from human bodily vulnerability is radically reduced if not altogether eradicated.[9]

Philosopher of technology Mark Coeckelbergh characterizes transhumanism as a distinctive "culture of vulnerability." Cultures of vulnerability are ways in which people and societies perceive and "give meaning to human vulnerability" (2013, 63). A transhumanist culture of vulnerability builds an inherent undesirability into the meaning of vulnerability and responds to it by adopting an attitude of technological overcoming, intervening at the level of individual bodies that are taken to require technological restoration or even radical enhancement. Coeckelbergh maintains that transhumanist efforts to overcome vulnerability are mere flights of fancy, oblivious to the ways in which technologies do not eradicate but rather "*transform* our vulnerability and create new vulnerabilities" (Coeckelbergh, 2013, p. 127; see the final chapter of Shew [2023] for a similar argument). He argues that we will always "Remain highly vulnerable entities given [our] fundamentally relational and dependent nature" (2011). In making this claim, he echoes relational approaches to vulnerability that are prominent in feminist philosophy. It is to this relational perspective that we now turn.

2.2 Vulnerability: A Relational Perspective

Feminist philosophers Mackenzie, Rogers, and Dodds [2013] offer a systematic analysis of the concept of vulnerability that starts with the identification of two general responses often given to the question "what is vulnerability?" The first response emphasizes vulnerability as an inherent dimension of human existence that stresses our common precarious embodied humanity and

[7]On stigmatizing framing of the use of assistive technology, especially in relation to those who are already perceived as less competent, see also Kamphorst and Anderson [2024].

[8]For an in-depth critical engagement with transhumanism, see Puzio (2022). The author criticizes, among other things, the argumentative structures of transhumanism, the problematic notion of a fixed "human nature", and the discriminatory implications of transhumanism, such as discrimination against women or people with disabilities. Transhumanism advocates for the enhancement of humans, yet it is driven by its own predefined ideals of improvement. It rejects illness, disability, death and aging, seeks to remove all vulnerabilities and contingencies, and idealizes a vision of the healthy, youthful human. Ultimately, even this human ideal is devalued in transhumanism when compared to the concept of the perfect machine.

[9]For a critique of how this reflects an ableist eugenic argument, see Shew [2023].

inescapable susceptibility to suffering. The second response uses the concept of vulnerability as a marker to identify those individuals (or groups) who are more susceptible to harm than others and who therefore require extra care. As Mackenzie et al. note, both responses have their shortcomings when considered in isolation. The problem with the first conception is that the emphasis on people's universally shared vulnerability threatens to obscure rather than encourage the identification of the context-specific heightened vulnerabilities and needs of particular groups or individuals within populations [Jacobs 2019; Mackenzie et al 2013]. The risk of the second response is that labeling specific people or groups as particularly vulnerable might lead to unwarranted and unjust paternalistic responses, stereotyping, disqualification, or discrimination [Jacobs 2019; Mackenzie et al 2013].

To overcome these problems, Mackenzie et al. [2013] put forward a taxonomy of vulnerability that integrates the above two responses by distinguishing between different sources of vulnerability, namely inherent and situational ones. As the term indicates, inherent sources of vulnerability originate from features inherent to the human condition: our corporeality, our neediness, our dependence on others, and our affective and social natures. The fact that human beings are embodied beings who need oxygen, nourishment, sleep and social interaction to function, is a prime example of an inherent source of vulnerability, as it makes humans inescapably susceptible to harm stemming from being deprived of oxygen, nourishment, sleep, or social interaction.

Situational sources of vulnerability, by contrast, capture the contingent social, political, economic, and environmental situations of individuals or social groups.[10] As such, attending to vulnerability might include considering the physical-material set-up of a person or group's physical environment, their social network, the degree to which they might be subject to societal stereotyping, the kind of work they do, the specifics of their insurance policy (or whether they have insurance at all), the geographical location of their dwelling, and so on. Thus, while all human beings are inherently dependent on oxygen, nourishment, and so on, it will depend on the area where one lives to what extent this dependency is emphatically felt, as the potential for harm stemming from this inherent dependency is heightened due to factors such as pollution, droughts, economic hardship, racially fraught infrastructure and housing policies, and so on. So, even though inherent and situational sources of vulnerability frequently manifest together, Mackenzie et al. argue for the importance of seeing these sources as analytically distinct in order to do justice to the idea that certain individuals or groups may indeed be more susceptible to harm and may therefore (justifiably) need additional resources, even if all human beings do share a common precarious embodied condition.

The taxonomy also brings out that sources of vulnerability can vary in their temporality, in the sense that some sources of vulnerabilities are short lived (e.g., a strained ankle), while others endure (e.g., an amputated limb). Recognition of this temporal dimension has practical utility in the design of assistive technology, for example for determining what materials to use for physical components (how durable, robust, flexible should the materials be for use over time?), for establishing adequate functional complexity of the technology (should the technology accommodate an ongoing process of rehabilitation?), and foreseeing expected use (in what contexts is the technology expected to operate?).[11]

Furthermore, Mackenzie et al. recognize that sources of vulnerability–both inherent and situational–can be *dispositional* (potential) or *occurrent* (actual). As an example, consider how the

[10]This aligns with capturing vulnerability in intersectional terms.

[11]The Jaipur Foot Prosthesis is a great example of an assistive technology that adequately reflects its socio-economic and cultural use-context. An extremely cheap and quick to make artefact, the Jaipur Foot, which is used by hundreds of thousands of amputees in the global south, is not only "well-suited for developing nations because it is cheap, enduring, and efficient. It is also culturally appropriate, by virtue of its design, as it enables its users to squat, sit cross-legged on the floor, and walk barefoot." [Srinivasan 2002, 328].

inherent source of vulnerability related to needing oxygen is generally dispositional until a situation arises– during a house fire, say–in which oxygen is lacking and the vulnerability becomes occurrent (but only for those individuals who are in the house at the time of the fire). Likewise, consider how a situational source of vulnerability like economic hardship is dispositional for most individuals who lack savings, but only becomes occurrent for those who suffer significant, unforeseen financial setbacks. This distinction between dispositional and occurrent sources of vulnerability can thus be helpful in analyses for distinguishing between potential and actual harm-ability.

The foregoing distinctions also help see that what counts as disabling, and what heightens one's vulnerability in one environment, might set one up for success in another environment. This is powerfully argued for by Sheri Wells-Jensen [2018] and Shew [2023] who discuss the advantageous position that could be enjoyed by blind and deaf astronauts who, if they were to be recruited in the first place, would be unaffected by "dim or failed lighting or vision loss from smoke" (Shew) or motion sickness. The upshot of such cases is that specific vulnerabilities must always also be analyzed relationally, by looking not just at individual body-minds, but at the interaction between a living embodied person and their environment.

Considering the relational can refocus the target area at which efforts to compute for vulnerability are directed. For instance, optimizing digital work environments can accommodate the needs of many people with limited or divergent mobility without targeting allegedly deficient bodies and without assuming that increasing physical mobility is even where people's priorities lie. As one of the co-authors of this article puts it: "I am sometimes asked why I don't arrange a better wheelchair or just use a wheelchair to go outside, however mobility as such is not my main current concern and also using a wheelchair, it's really physically unpleasant."

Similarly, while apps and tablets might equip non-speaking autistic children with the functionality to utter important speech acts (such as "no, I don't like this") that help protect against a range of harms, the degree to which these devices contribute to non-speaking autistic children's ability to not only express themselves but also to be genuinely *heard* by their social environment has been shown to be shaped by relational factors, differing radically along axes of race and class [Alper 2017]. For instance, as Meryl Alper's research shows, the ability to give expression to one's cultural identity and blend in with one's cultural community when using a speech generating app can be more challenging for children from certain cultural backgrounds in comparison to others, as "engineers, with limited conceptions of what it means to talk and what "natural" speech sounds like for an "average" person, whisper beneath every inflection of synthetic voice." [Alper 2017, 63]. In these kinds of instances, a technology, while mitigating certain vulnerabilities (for instance, by providing the possibility to say "no"), simultaneously introduces or exacerbates other vulnerabilities, such as one's vulnerability as a person who thrives via community membership but whose assistive technology emphatically differentiates one from one's community in highly salient ways. Thus, taking into account the broader context in which a person is embedded and the various relational dimensions a person maintains with the environment can help foresee, and ideally avoid or mitigate, certain pathogenic vulnerabilities that are more readily overlooked from the individualist perspective.

At the same time, it is important to remain cognizant of the possibility that pathogenic vulnerabilities can also be created by focusing solely on the relational. One potential pitfall with this perspective, for example, is that it risks downplaying genuinely valuable individualistic interventions. Sometimes we can suffer or be harmed in ways that are best mitigated by locating the source of that harm or suffering at the level of the individual. Arguably, a relational perspective can get in the way of effectively mitigating the vulnerability entangled with such harm and suffering.

Another potential pitfall is having insufficient appreciation of people's agency, in the sense of considering particular predicaments as unfortunate but inescapable results of circumstance.

Certainly, seeing how a person's particular elevated susceptibility (e.g., due to low digital literacy, or due to a missing limb) to particular kinds of harm (e.g., missed financial benefits, or missed employment opportunities) is linked in significant ways to situational sources of vulnerability (e.g., the socio- economic milieu one grew up in, or the wheelchair-unfriendly physical environment one resides in) can be instrumental in both understanding and mitigating this kind of vulnerability (e.g., by offering accessible educational programs, or by improving wheelchair access). However, care has to be taken not to fall into the trap of framing individuals in these situations as helpless victims in need of salvation. For such paternalistic framings–akin to the ones discussed in Section 2.1–will lead to higher susceptibility to harm stemming not only from (a potentially debilitating) sense of victimhood but also from (self-)stigmatization. Striking the right balance between, on the one hand, recognizing the significant adversities and externalities people in difficult circumstances face, and, on the other hand, the power they do have to shape the direction of their lives, is paramount.

A different potential pitfall of the relational perspective has to do with the ways in which adjustments to the wider societal context in response to observations stemming from the relational perspective may, in some circumstances, have undesirable consequences for other members of the community, effectively creating sources of vulnerability for others. Consider again the relational insight that speech assistance technology for people with communication disabilities may inadvertently place them outside of their cultural communities. Attempts to improve this situation can be located at the level of the technologies (e.g., modifying the speech technologies such that their inflections and vocabulary can better adapt to and express cultural nuance) or at the level of the community (e.g., promoting norms to speak with a strictly shared but limited vocabulary and inflection). While the latter adaptation may in some communities be quicker and cheaper to accomplish than a difficult-to- implement technological improvement, it could lead to a situation in which community conversations become impoverished and the majority of the community members feel culturally alienated. Thus, the pitfall for designers to avoid here is adopting the naive assumption that identified relational conditions that play into one person's vulnerability straightforwardly make suitable, appropriate, and desirable targets for interventions at that level. Given the shared nature of many relational factors (community norms, workplace conditions, etc.), caution has to be taken to carefully consider the wider socio- relational context when designing mitigation strategies that target such factors.

Lastly, the relational perspective shares a pitfall with the individualist perspective, namely its underappreciation of the ways in which sources of vulnerability are bound up with sources of meaning-making. As the third perspective will highlight, sources of vulnerability can under certain circumstances and conditions offer affordances for creative innovations that contribute to how (disabled) people make sense of, and create meaning in, their environment. Focusing solely on the ways in which the environment contributes to harm-ability thus means possibly missing opportunities to add value beyond the mitigation of potential harms.

These examples of pitfalls are not meant to be exhaustive, but they serve to illustrate the point that shifting from an individualist perspective to a relational perspective is not in and of itself a full- proof protective measure against pathogenic vulnerabilities. Rather, as we will continue to argue in Section 3, the take-away is that each perspective contributes to a richer understanding of the design question and its context. First, however, we will turn to the third and final perspective.

2.3 Vulnerability: An Enactivist Perspective

The inherent vulnerability highlighted by the relational perspective on vulnerability is also foregrounded in recent *enactive* developments in cognitive science, which build upon insights from biology to explain how living beings, including human beings, are able to experience and give

meaning to the world in which they are embedded. In this section we will offer a sketch of this enactive approach, as it opens up a perspective on vulnerability that is missing from the previous two perspectives (different though they may be), namely one that presents *vulnerability as intimately bound up with processes of meaning-making*. Adopting a perspective on vulnerability as bound up with meaning- making can open up creative new approaches to computing projects that aim to be responsive to human vulnerability, or so we argue. Furthermore, this perspective can help avoid or mitigate certain pathogenic vulnerabilities that might result otherwise. Ultimately, though, as we have been indicating, each of the three perspectives on vulnerability speak to something truthful about the human condition and would therefore likely benefit R&D processes if considered throughout.

Central to this perspective is a commitment that vulnerability as a phenomenon is only applicable to systems of a certain kind, namely *systems that are, by their very nature, open to an environment they are dependent on for their functioning*. Insights from embodied cognitive science highlight that, in the case of living systems, such functioning is marked by a logic of recursive self-constitution: a living system (i.e., an organism) is by its very nature in the business of actively constituting itself and remaining viable as a unified bounded autonomous system via an openness to, and dependency on, features of the environment. Consider, for instance, the example of a single cell organism. A cell is a "spatially individuated whole" separated from and connected to its environment in virtue of a semi- permeable boundary (its membrane) [Thompson 2007, 99]. This semi-permeable boundary exposes the cell to its environment, allowing for exchanges that the system needs in order to continue to function as a spatially individuated metabolic system. These exchanges, in turn, enable a constantly regenerated boundary within which the cell's metabolic processes unfold and without which meaningful exchanges with the environment would not be possible. In the words of biologist, philosopher, and neuroscientist Francisco Varela, "[a] living system must distinguish itself from its environment, while *at the same time* maintaining its coupling," where coupling "refers to the necessary and permanent embeddedness and dependency of the self on the environment" (1991, 85, and 103).

The vulnerability of living beings, including human beings, thus stems from their nature as porous self-constituting entities, embedded in and dependent on the availability of resources of the environment to remain viable as self-constituting systems. Because the environmental resources offered by the environment are always partly outside of their control, living systems are inevitably exposed to conditions that might harm or jeopardize their integrity as bounded yet environment-dependent systems. They are, in other words, inherently vulnerable. What is crucial from an enactive embodied perspective, though, is that the very same conditions of ontological exposure and dependency account for a living system's meaningful responsiveness to its environment. The precarious embodiment of living beings and their exposure to their environment inevitably means that environments *matter* to living selves; it is meaningful to a living self from its vulnerable embodied perspective. Furthermore, exposure to and dependency on an ever-changing environment inevitably comes with moments of adaptively repositioning, thus motivating an organism to reestablish itself and its meaningful relationship with its world, frequently in new and improved ways [cf. De Jaegher and Di Paolo, 2007]. In other words, what makes living beings, including human beings, capable of perceiving, responding to and creating meaningful worlds is the fact that they are never self-enclosed and radically independent, but always in need of resources residing outside the precarious boundedness that is characteristic of their bodily existence.

The insights from this area of research, we contend, carry over to discussions around human vulnerability, and what responsible computing for human vulnerability requires. Unlike the above example of the relatively simple metabolic system, human beings are deeply social, have feelings and language and have profoundly transformed the environment within which they navigate their

lives (through the creation of technological tools, legal systems, cultural practices, economic infrastructures, etc.). This means that human beings are open to and dependent on their environment in a multiplicity of ways, exposing them to various types and sources of vulnerabilities through different interplays between aspects of the individual and aspects of the environment in which they find themselves. These types and sources of vulnerabilities, i.e., these ways in which the integrity of a precarious environment- dependent system can be destabilized in potentially harmful ways, can affect humans as the embodied, cognitive, affective, economic, social, technological, and so on beings they are.

From an enactive perspective, such potentially harmful destabilization is typically not undergone passively, but actively responded to in a manner that can fuel new forms of meaning- making.[12] We posit that efforts to compute for vulnerability, e.g., through assistive technology, should embrace methods that can help to acknowledge and uncover the meaning-making dimensions of our embodied lives and the ways in which sources of heightened vulnerability, such as disability or old age, are never reducible to lack, loss, and harm, but often at the same time count as sources of new meaning-making [Van Grunsven 2024].[13]

This insight, in turn, can open up new, creative, and respectful technologies. Consider, for instance, the example of young amputee Jordan Reeves, who collaborated with a designer to make her ideal prosthetic arm: not a smooth-functioning bionic arm but a glitter-shooting unicorn! As evidenced on Reeves' website and in the many media appearances that covered the glitter-shooting unicorn creation, Reeves shows how the arm, which signifies the opposite of deficiency and troubling vulnerability, brings joy and opportunities for shared meaning-making with other kids (how cool is it to have a classmate who can sprinkle you with glitter that shoots from their arm?!).

We see similar efforts in the space of assistive communication. Several HCI researchers have proposed ways to center autistic forms of embodied communication and meaning-making in the design of assistive communication technologies. Many autistic people enjoy self-stimulatory acts, such as rocking, flapping, or humming. While traditionally labeled as pathological, meaningless, or non- communicative, testimonials from autistic people as well as participatory research with autistic people reveals that stimming can in fact be a richly communicative form of meaning-making [Kapp et al. 2019]. Digital technologies can help to facilitate interactive spaces in which autistic stimming is honored and supported for its meaning-making significance. For instance, the "magical musical mat" can facilitate a space conducive to interactive stimming, through the linking of interpersonal touch with sound. As Rachel Chen observes, "foregrounding interpersonal touch eventually guides parents into their children's sensory activities where parents attune to the stims of their children by joining in and facilitating their expressiveness, co-creating extended, evolving patterns of repetitive cycles" [2024].

These examples show how a rejection of interventionist strategies aimed at restoring or mitigating "deficient" autistic communicative functioning can open up space for celebrating different, neurodivergent ways to communicate and interact with the world–forms of meaning-making that technologies can support [See Mankoff et al 2010; Williams et al. 2023; Van Huizen et al. 2023; for

[12]A somewhat similar argument is also made by Matthew Congdon [2023], who highlights that the precarious human condition and the ability to be and feel harmed can also lie at the root of the human drive to creatively and dynamically "articulate" new moral concepts with which we give meaningful expression to our human condition.

[13]See IJsselstein et al. [2020] who propose a "Warm Technology" approach for designing with and for patients with dementia in a way that does not just approach them in terms of lack, loss, and deficiency in functioning but also identifies opportunities of meaning-making See Fletcher-Watson et al. [2018] for a proposal, explicitly grounded in enactive embodied sense-making, on how to compute for diverse embodiment. See Dokumaci [2023] for an ethnographic account of how people with arthritis creatively tinker with their social and material environment to make sense of and with their worlds in ways that make those worlds more amenable to them.

philosophical substantiations see Van Grunsven and Roeser 2022]. They underscore the importance of taking seriously the situated know-how of the users of assistive technology, and ensuring that these technology users are never merely seen in their ability to be harm-able but also in their capacity as meaning-makers. Rather than working on the basis of presumed deficiency and rather than assuming that we already know how their needs are best responded to with assistive tech, creative new ways of designing assistive technology can be arrived at that places the lived experiences and know-how of its users at center stage (Shew and Van Grunsven forthcoming). This creativity can be opened up by seeing how human being's entanglement with the world not only exposes a variety of possible harms but also facilitates processes of meaning-making.[14]

That said, like with the other two perspectives, there might also be potential pitfalls to the enactivist meaning-making perspective when considered in isolation. One particular worry is that the perspective could lead to a romanticization of vulnerability, with real exposures to harm being overshadowed by their redeeming quality of opening up new forms of meaning-making. Such a view could create pathogenic vulnerabilities in the sense of diminishing the lived experiences of people in dire circumstances where there are no silver linings or where the safeguarding of more urgent basic needs must be prioritized over encouraging new possibilities for meaning-making. Moreover, the perspective also risks being co-opted by a neo-liberal argument for self-reliance (see Dokumaci [2023] who addresses a similar concern).

Additionally, there are moments and contexts in which identifying and mitigating lost, absent, or hampering forms of functioning at the level of the individual, and thus working with a more individualist perspective on vulnerability, might need to be prioritized (e.g., to ensure that non-speaking AAC users have access to the ability to say "No, I don't want this"). One could worry that a single- minded focus on meaning-making distracts from those priorities ("we don't all want to walk around with glitter-shooting unicorns for arms"). We emphasize, though, that making choices about how vulnerability is best approached is not a zero-sum game; operating with multiple perspectives on vulnerability can help to assess what is realistic, feasible, and desirable in a given context. Still, while the meaning-making perspective can come with its own set of risks when considered in isolation, we do advocate for an assessment process that includes, from the start, the lived meaning-making perspectives and know-how of the users of assistive technologies.

3 Designing for Human Vulnerability: Engaging with Three Perspectives

By identifying and putting forward three perspectives on vulnerability–i.e., the individualist, the relationalist, and the enactivist meaning-making perspective–we have aimed at showing how the way in which vulnerability is conceptualized has direct bearing on how it is operationalized in computing projects. We have furthermore aimed at showing the importance of fostering a critical awareness of these different but complementary perspectives. For engineers in the field of responsible computing, it is key to be able to adopt all three perspectives and explicitly and critically reflect upon what each perspective or combination of perspectives brings to the design context and project aims. While we take it as foundational that the lived experiences and perspectives of direct stakeholders are to be incorporated and valued from the start, we have also shown that each approach, when taken in isolation, can run the risk of creating new vulnerabilities or exacerbating existing ones. As such, there is no clear-cut hierarchy of which conceptualization is "better", and it will depend on a specific situation how insights from each perspective will translate into

[14] In a current project (anonymized for review) some of us are investigating the idea of human-machine alignment dialogues by assuming that human beings need an interactive process of meaning making. This in turn is motivated by the assumption that a machine can never fully capture all relevant aspects of the supported person, because support is highly contextual and dynamic.

practice. That said, we wager that in our current Western sociotechnical climate the strong emphasis on individualistic approaches to vulnerability in the context of assistive technology warrants special attention and we should be especially mindful of the pitfalls associated with this perspective. Furthermore, we wager that it is typically preferable to adopt a perspective on vulnerability that builds upon the relational and meaning-making lives and lived experiences of users. With an eye to this effort, we believe that the three perspectives we have outlined can together function as a heuristic tool in the design process by providing a vocabulary to support the articulation of different vulnerability dimensions in design contexts.

For clarity, we have represented the three perspectives in the Table 1 below.

An important remaining set of questions revolves around procedurally implementing the use of the three perspectives into design processes. While we do not yet have best practices to share, we would like to (1) outline promising connections between our proposal and existing research on participatory and critical design, and (2) posit the need for a dynamic, flexible approach to vulnerability-responsive technology. We conclude by calling for further engagement with these ideas from the responsible computing community (in Section 4).

3.1 Calling for Critical Participatory Design Approaches

We begin by making a general observation pertaining to methodology. If, over and above the individualist perspective, the relational and enactivist perspectives are to be adopted in earnest, there will need to be more genuine engagement in the field of responsible computing with the individuals for whom a technology is being designed for. This is not a new point of course, but since experts-by- experience, and particularly those from marginalized communities, are still routinely ignored in technology design, it bears repeating. Designing "for" vulnerability or "with" vulnerability in mind thus points to some form of participatory design [Bødker et al. 2022], as participatory methods are "meant to engage researchers in the reŋflection necessary to center the needs of the people over their own assumptions" [Williams et al. 2023].

We must, however, give note to the growing body of literature that critiques participatory methods [see e.g., Lysen and Wyatt 2024; Chilvers and Kearnes 2016; Nielsen and Boenink 2020]. Key points of critique on participatory methods include "the power imbalances in participation projects, which may perpetuate exclusion and marginalization of certain groups because of unequal accessibility to forms of participation, a disparity between participatory ideals and actual results, and a depoliticization of people's representation" [Lysen and Wyatt 2024]. Various (feminist) STS scholars have argued that responsible innovators and researchers should strive for a critical engagement with participation itself by taking on a reflexive approach to participatory design practices. Such a reflexive approach entails addressing how researchers themselves are constituted in the research project, the ways in which they are not only teaching but also learning from the stakeholders involved, and what power, resource or other asymmetries may characterize the contexts within they seek to intervene [Conley and York 2020 cited in Lysen and Wyatt 2024.] One might say that researchers in participatory design projects must allow themselves to be vulnerable within the design process.

Let us briefly put forward two promising participatory approaches as exemplary models of designing *with* vulnerability. One such example is the reflexive approach to the design of embodied AI from a **diversity, equity, and inclusion** (**DEI**) perspective, developed by Zaga et al. [2022]. Central to their approach are various tools and techniques to promote reflexivity among researchers and designers of embodied AI. One of these tools–an illustrated template with a set of guiding questions– aims at facilitating explication of implicit assumptions present in a research or design team, such as implicit assumptions on gender or ableism. The template guides teams through a two-step activity. First, teams are stimulated to examine current scenarios and AI artifacts that

Table 1. Three Perspectives on Vulnerability

THREE PERSPECTIVES ON VULNERABILITY		
Individual vulnerability	**Relational vulnerability**	**Enactive vulnerability**
Definition Sees vulnerability as harm-ability and locates sources of vulnerabilities at the level of individual users' embodiment (e.g., missing limbs, deficient hearing or sight, lacking communicative abilities).	**Definition** Sees vulnerability as harm- ability and locates sources of vulnerabilities at the intersection of individual and context (that is, the individual in relation to the social environment, material environment, cultural norms and practices, intersectional power dynamics, etc.).	**Definition** Sees harm-ability as a necessary consequence of being an embodied embedded, meaning-making being, and holds that sources of vulnerability, as harm-ability, are typically also intimately bound up with processes of meaning-making.
Mitigating vulnerability Focuses on restoring lost or deficient functioning, while working on the basis of a genderless, ageless, ahistorical, unsituated understanding of "normal" or "adequate" embodied functioning.	**Mitigating vulnerability** Considers interventions in relation to situational factors, taking into account the intersectional and environmental specifics of embodied beings.	**Mitigating vulnerability** Considers how sources of vulnerability are entangled with meaning-making processes of a specific individual, and looks to make changes within a specific environment that are meaningful to that individual or help that individual to create meaning.
Example cases • Bionic prosthetic limbs built upon normative view of "natural embodiment". • Assistive communication tech aimed at restoring communication deficiencies located "in" the autistic individual.	**Example cases** • Environmental factors that make prosthetic limbs accessible and desirable (e.g., the built environment, insurance policy). • Assistive communication tech that incorporates cultural and social signifiers that enable users to express their cultural identity and be better embedded within their cultural communities.	**Example cases** • Prosthetic limb that acts as a source of meaning-making and brings joy to the individual and the community (e.g., the glitter-shooting unicorn). • Assistive communication tech that celebrates autistic sense-making (e.g., stimming).
Pathogenic Vulnerability Pitfall • Risks overlooking broader societal structures that determine how a source of vulnerability is experienced. • Risks stigmatization for not being "normal". • Risks devaluing voices of those who are experts by experience.	**Pathogenic Vulnerability Pitfall** • Risks attributing too little agency. • Risks paternalistic interventions. • Risks naive relational mitigation strategies. • Risks overlooking possibilities for creative meaning-making.	**Pathogenic Vulnerability Pitfall** • Risks romanticizing vulnerability. • Risks being co-opted as an argument for (ever- more) self-reliance. • Risks overshadowing more urgent basic needs.
Methodological tendencies • Prioritizing technological and scientific expertise. • Disciplinary problem- solving.	**Methodological tendencies** • Social (critical) analysis. • Stakeholder analysis. • Listening to voices of marginalized groups.	**Methodological tendencies** • Participatory design. • Listening to voices of marginalized groups with an emphasis on meaning-making in their experiential lives. • Transdisciplinary practices that incorporate art to address and reframe experiences of vulnerability.

embed narratives, biases, and stereotypes. Second, the teams are invited to speculate on how future AI will interact with existing systems, who will be involved and potentially co-opt. A tool like this could likewise help make explicit what perspective on vulnerability members of a research or design team (implicitly) hold. Another tool described by Zaga et al. [2022] is that of mapping privileges, such as gender or education, on a two-dimensional axis. This activity aims at provoking discussion and reflection on how one personally experiences privilege (or the lack thereof) and how one attributes privilege to others. This can be a powerful way, at the start of a participatory process, to make visible and reflect upon how participants and members of a research or design team see themselves and how they assess the social positions of others.[15] This conversation starter could be extended to make visible which sources of vulnerability participants identify, how participants experience their own vulnerabilities, and what difficulties or harms they experience as well as the privileges and enrichments they experience in their lives.

Another powerful critical participatory approach to designing with vulnerability can be found in the work by Williams, Boyd. and Gilbert [2023] who describe a transformation of the second author Louanne E. Boyd's perspective on designing assistive technology for people with autism. Through "reparative readings" of four prior research projects by Boyd on HCI interventions in the context of autism, the authors closely explore the transformation of Boyd's body of HCI interventionist work as it moves from an individualist perspectives on autistic vulnerability (a need for improvement in social skills and social interaction with help of technological assistance) to a plurality of participant-informed possibilities. The technique of "reparative readings" comes from practices in queer media studies and aims at disentangling a legacy of harm such that alternative practices for a more just future may be made legible [Sedgwick 1997]. The authors conducted their reparative readings of the four prior projects by reflecting "on the undergirding motivations for support and social transformation to reinterpret tensions between normalizing and curative approaches to disability technology and the surprising interactions between participants and researchers that alternately contest and affirm the potentialities of these projects" [Williams et al. 2023]. With this carefully documented shift in perspective from an interventionist and restorative approach to a participatory approach, the authors illustrate how this new perspective opens up different design choices that are more respectful of and in line with the desires and needs of the people they aim at supporting.

We propose that our three perspectives can help bolster such efforts. We suggest that oscillating between the perspectives, especially in smaller design teams, can offer a comprehensive way for researchers and designers to systematically reflect on their own attitudes and assumptions about vulnerability and the degree to which and ways in which their design practices and processes make room for vulnerability. For larger teams, it may be feasible to have dedicated roles whose responsibility it is to adopt one of the perspectives and bring that perspective to the design problem at hand. In this context, we foresee a need for protocol, guidelines or a set of guiding questions to help structure this process and formalize responsibilities.

A promising starting point in this area could be Williams et al.'s [2023] *five principles* for analyzing and building "counterventional modes of research inquiry". They use the term *counterventionn* to describe intervening on "the practices of interventionist science toward critical and liberative insights into new ways of engaging with disabled people" [Williams et al. 2023]. A counterventional approach to research inquiry can best be understood as a means "to manifest epistemic transformation within the research team and their professional communities as a result of critical

[15]Interesting to see is whether these self-assessments of privilege correspond with how the other members assess that person. Do people assess someone's positions of privilege higher or lower than how the person herself reflects upon this, and if so, what is it that leads to this perceived mismatch?

reflection and engagement with the broader historical, cultural, and social legacies of the particular design space" [Williams et al. 2023]. Five principles are formulated by Williams et al. [2023] to help designers to simultaneously reveal and resolve flaws in the implenmentation and interpretation of intervention design and outcomes. The aim is to compel them to reflect on how their own research and development practices may construct misconceptions about the lived reality of vulnerable subjects.

The first principle is to "reflexively engage with the participant community" [Williams et al. 2023]. As Williams et al. critically point out, "it is possible to conduct participatory rensearch with marginalized subjects that does not question dominant societal assumptions about that participant group" (p. 7). In particular, research with vulnerable and disabled participants commonly centers the authority of the researchers or clinicians and easily fails to acknowledge bias and presumptions. Since such assumptions can play a decisive role on how vulnerability is conceived and designed for, attention is needed to build reflexivity into Research & Development (R&D) processes. To this end, Van Grunsven and IJsselsteijn [2022], for instance, propose using critical design tools to reflect on biases and entrenched habits in how technologists perceive and design for–and with–disabled people. Such critical *Reflexive* engagement renquires a commitment to humility, surprise, and discomfort, which is much needed in order to avoid the critique on participatory design methods mentioned above [Lysen and Wyatt 2024]. This, in turn, might require explicitly and reflectively embracing the role of emotions in processes of participatory design and making room for this in engineering and design education curricula [Roeser 2012]. Moreover, it demands an openness to developing new alternative methods for stakeholder engagement capable of meeting differently situated marginalized stakeholders (e.g., non-speaking autistic children) on their own terms [Van Goidsenhoven and De Schauer 2020; 2022; Van Huizen et al. 2024].

The second principle Williams et al. [2023] offer is to "critically examine disconnects between intervention and participants' desires", (p. 7), which requires a conscious assessment of what participants imagine and do for themnselves outside of contexts of clinical care [Hamraie and Fritsch 2019; Van Dijk et al. 2019]. Designers, for example, might lean too heavily on an individualist, interventionist perspective on vulnerability while an enactivist, meaning-making perspective could facilitate the participant's desires better in the design context at hand. Being able to critically reflect upon and oscillate between the three perspectives on vulnerability will help designers to put this principle into practice and mitigate the risk of any disconnects between their innovation and participants' desires.

The third principle is to "interrogate the political entanglements that construct the intervention domain". When researchers remain uninformed about the social and material realities of their participants, they risk producing solutions that are doomed to fail or that may exacerbate vulnerabilities; a worry also highlighted by the relational perspective on vulnerability.

The fourth principle is to "develop an intervention as a self-critique of these disconnects and entanglements", which is to actively draw out the disconnects between participants' densires and prior work, making visible the historical and social context that prior work has left hidden.

The fifth principle is to "privilege participant experiential testimony in the evaluation of outcomes", which is vital to avoid the concern that a project can claim success while leaving hidden possible harms that participants were not given the chance to voice.

As mentioned, these five principles could help structure the process of bringing into focus the three vulnerability perspectives in the innovation trajectory. Conversely, our three vulnerability perspectives could provide resources for putting these principles into practice. We call on the wider community of responsible computing scholars and practitioners to help further develop such tools.

3.2 Calling for a Dynamic, Flexible Approach to Vulnerability-responsive Technology

Finally, what the work on vulnerability shows is that vulnerability is not a static state. Its sources are manifold, its way of making an appearance dispositional and occurrent, and its significance intertwined with human beings' precariously harm-able as well as meaning-making lives. One important implication of this is that designing for vulnerability should be considered an ongoing, dynamic process, one that is not finished when a product is delivered or fitted. Rather, we suggest that designing for vulnerability entails a rethinking of the boundaries between, on the one hand, design and innovation, and, on the other hand, implementation, maintenance and an ongoing responsiveness and adaptability to the lives of users. The degree to which an assistive technology requires ongoing monitoring, adjusting, and responsiveness to the user's vulnerable sense-making life will vary on a case-by-case basis, and reflecting on these matters throughout the design, implementation, and maintenance process can be fruitfully informed by the three perspectives on vulnerability that we have proposed here.

One development worth mentioning in this context is research into *run-time* approaches to computing with vulnerability (author under review). Such approaches take seriously the idea that assistive technologies have to be able to adapt dynamically not just to the physical and mental state of the user but also to changing environmental factors, social norms, and other relevant aspects of the user's context.[16] Development of such vulnerability-aware digital technologies might build on research on norm- and value-aware (personal) agents, which employ computational models that capture aspects[17] of human being's values, preferences and context in order to enable support that continuously adjusts [see also Wolff et al. 2024] to a person's changing needs as interactions and experiences unfold. A starting point for creating such computational models could be research on software that takes into account personal norms and values [e.g., Van Riemsdijk et al. 2015], as well as habits and capabilities [e.g., Kliess et al. 2019; Berka et al. 2022; Zhang et al. 2022]. Also relevant are models for expressing and accounting for social agreements that the digital technology should adhere to [e.g., Kayal et al. 2018; Kola et al. 2022] and work on alignment dialogues to support interactive human-machine meaning making [e.g., Chen et al. 2023; for the importance of human-machine alignment, see also Kamphorst and Kalis 2015]. Moreover, such approaches could be used to promote awareness with users about their own and others' vulnerabilities (as part of relating), by stimulating reflection on their experience and needs in the moment.

These are, of course, just some of the ways in which our proposal aligns with and offers new insights for the field of responsible computing. The need to reflect on these insights and operationalize them in concrete design contexts will continue to be an ongoing process, given the dynamic and multivarious nature of human vulnerability.

4 Moving Forward

In response to the increasing interest in the field of responsible computing in vulnerability, we have aimed at drawing out the multi-dimensionality of the concept of vulnerability in order to deepen and enrich the conversations about the relationship between vulnerabilities and (the design of) assistive technologies. We have introduced three perspectives on vulnerability–the individualist, relationalist, and enactivist perspectives–that each emphasize a different aspect of what

[16]For the importance of defining and understanding context in relation to assistive technology, see, e.g., Van Wissen, Kamphorst, and Van Eijk [2013].

[17]We emphasize that in our view, human vulnerabilities cannot be fully captured in computational models due to their fundamentally human embodied and contextual nature. However, we suggest that some aspects might be modeled in ways that are sufficient for providing vulnerability-aware support to people in specific contexts.

it means to be vulnerable. We have argued that, when used in conjunction, the three perspectives together may go some way toward mitigating the risk of creating technological interventions that aim at ameliorating vulnerabilities but instead exacerbate or create new ones (pathogenic vulnerabilities).

In introducing the three perspectives, we have drawn on various literatures to enrich the vocabulary around vulnerability and to add critical distinctions to the responsible computing discourse. Throughout, we have relied on the use of concrete examples from the space of assistive technology with the aim of firmly establishing the relevance of adopting each viewpoint in design processes, even for those less convinced of relational ethics or enactivist cognition.

The distinctions we have brought to the fore also bring out–as an additional benefit–that designing for vulnerability need not only be equated with designing for marginalized groups. Although we have focused in our examples on marginalized groups, acknowledging the inherent sources of vulnerability stemming from what precarious embodied humanity has in common reveals that considering the myriad ways in which technologies can affect vulnerability will likely benefit the design of other human-facing technologies. Understanding at a fundamental level that all human beings, through their embodiment and engagement with the world, experience forms of vulnerability (everyone ages, everyone experiences accidents), helps see that we all stand to benefit from a society that is designed for vulnerability.[18]

All in all, we hope to have shown how a more fine-grained understanding of vulnerability might further enable the design of technologies that in fact acknowledge (and in some instances value) people's vulnerabilities and their diverse abilities and forms of know-how, which enables researchers from the field of computing to embark on projects that play into people's strengths. We have noted how several proposals in this direction have been made in the HCI literature, but also how these have thus far not become firmly ingrained in today's design practices. To move forward, we call for further reflection on how to best integrate the three perspectives on vulnerability into participatory design practices, how to distribute responsibilities within design teams to ensure that all perspectives are genuinely adopted and engaged with, and how to foster creative, out-of- the-box thinking for assistive technology design. We also invite scholars to reflect on the limits of creative design, recognizing the limits of public resources, but also the pitfall of reinviting an overly technology-oriented framing which again seeks to "fix shortcomings or deviations," only through highly creative means.

Beyond this call for further reflection, we call for research communities and stakeholders to come together and critically engage with the ideas presented in this article. We encourage sharing resources and experiences, and establishing a shared foundational understanding of the intricacies of designing products that (1) protect against exploitation of vulnerabilities, (2) prevents the exacerbation or creation of vulnerabilities, and (3) recognizes and celebrates the diverse ways in which people make meaning of and with their world as precarious embodied and environment dependent beings.

[18]There are different ways to make the case that designing for vulnerability of marginalized individuals and groups also benefits the non-marginalized. Some of these arguments point to the widely shared benefits of universal design (e.g., how ramps benefit not only people with mobile disabilities, but also ageing people, wobbly toddlers, parents with strollers, people with temporary injuries). Other arguments opt for a more psychological route, arguing that human beings are empathetic creatures who cannot fully flourish in a social world that invariably does not take into account the needs of the most vulnerable (See Pickett and Richard Wilkinson 2009). We flag, though, that this line of argumentation seems empirically contestable. Furthermore, research on human empathy is itself guilty of definitional and methodological confusions and flaws that have greatly contributed to heightened undesirable vulnerabilities in the lives of autistic people [Bollen 2023].

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