On the Margins of the Machine: Heteromation and Robotics

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Abstract
Growing interest in robotics in policy and professional circles promises a future where machines will perform many of the social and institutional functions that have traditionally belonged to human beings. This promise is based on the premise that robots can act autonomously, without much support from their human users. Close examination of current social robots, however, introduces a different image, where human labor is critically needed for any meaningful operation of these systems. Such labor is normally unacknowledged and made invisible in media and academic portrayals of robotic systems. We take issue with this erasure, and seek to bring human labor to the fore. Drawing on the concept of "heteromation," we illustrate the indispensible role of human labor in the functioning of many technological systems. Given current uncertainties in the robotic design space, we explore various scenarios for the future development of these systems, and the different ways by which they might unfold.

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1 Introduction

In 1955, science fiction author Philip K. Dick wrote "Autofac," a short story about autonomous machinery. After a devastating war, humans discover that machines are restarting themselves and working on their own projects. "'They're building,' O'Neill said, awed. The machinery was building a…replica of the demolished factory." In the early days of robotics, in the 60s and 70s, the main aim and problematic of the field were quite similar to Dick's notion of the autofac: the ideal was to produce autonomous machines. An instance of this ideal was the notion of the "lights-out factory" in which robots operate 24 hours a day, in the dark. Another was the "dark NOC" (network operations center) in which machines manage themselves autonomously to run telecommunications networks. Dick placed his autonomous machines underground, prefiguring the motif of darkness and its peculiar appeal to engineers inventing autonomous machines. Although early AI recognized that some minimal human intervention would be needed to make machines work (it was not, after all, literally science fiction), Dick's story anticipates a theme that animated AI for decades and continues to inform how we think about the potencies of digital machines (Ekbia 2008).

The ideal of the lights-out factory and the dark NOC never came to practical fruition, and as the industrial robotics market reached saturation, governments in the US, Japan, and Europe started looking for other application areas for robots outside manufacturing, operations, and research. These have, inevitably, been in less structured human environments, including homes (Gates, 2007; Sung et al., 2007), offices (Huttenrauch et al., 2004; Tsui et al., 2011), schools (Kanda et al., 2007; Tanaka, Cicourel & Movellan, 2007), malls (Kanda et al., 2009), hospitals (Mutlu & Forlizzi, 2008), and eldercare facilities (Broekens, Heerink, & Rosendal, 2009; Inoue et al., 2010). The development of robots for these kinds of environments brought out existing problems in robotics and AI regarding machine function under conditions marked by significant uncertainty in dynamic environments.

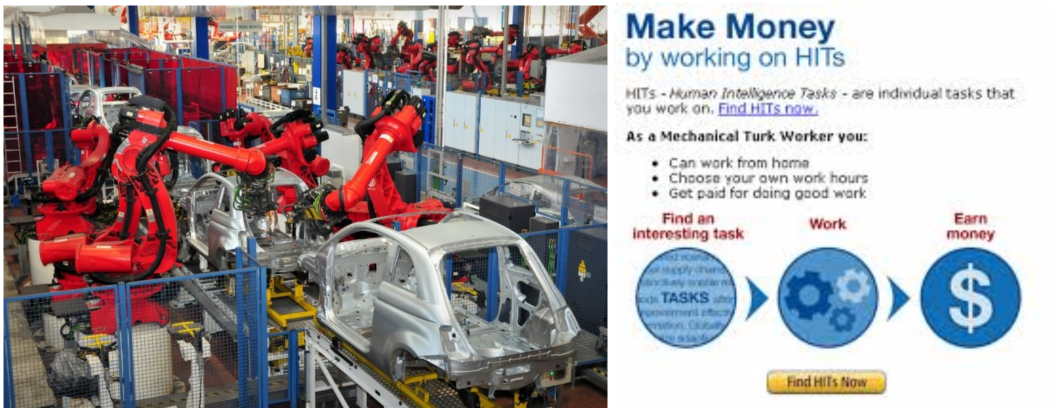
One way to address such conditions would be to precisely specify the tasks a robot does, but robots have been generally envisioned as more general-purpose machines. Another proposed solution is instrumenting human environments so that they are more habitable and comprehensible for robots (e.g., placing fiducial markers in strategic spots, RFID tags on objects, or using ramps rather than stairs). The potential popularity or practicality of this approach is, however, questionable, since it involves both the cost of retrofitting existing spaces and design choices that may not fit human preferences (Auger, 2014). A third solution that is increasingly being pursued is to design collaborative arrangements for humans and robots that will allow robots to function successfully in human environments, and provide services that are beyond the capabilities of current technical know-how alone.

The NSF's National Robotics Initiative (NRI), which has been running since 2012, is centered around the development of "co-robots acting in direct support of, and in a symbiotic relationship with, human partners" (National Science Foundation, 2014). This funding mechanism has been seen as a boon for the field of human-robot interaction (for a review of the field see Goodrich & Schultz, 2007), since it posits that one side should not be thought of without the other. The notion that robots could (and should) rely on human capabilities to help them achieve their tasks has been around before. The concept of "sliding autonomy" or "shared control" (Crandall & Goodrich, 2002; Sellner et al., 2006) asserts that robots can be partially autonomous, performing things they know how to do by themselves, but asking for human help when they need it, like when an image needs to be identified, a set of choices disambiguated, or a difficult navigation problem solved. Teleoperation has always involved some level of mixed autonomy since it is cognitively burdensome and inefficient for the person to control all movements of the robot. It is better if the robot can navigate the local environment and avoid obstacles, for example, while the person gives the robot general directions or goals for where to go, or takes over when the task becomes overly complicated, such as when the robot needs to talk to people (Kanda et al., 2009). There are many situations in which human-robot teams of various compositions are seen as necessary or likely, including urban search and rescue (USAR), assistive robots used in healthcare, educational robots, drones, and even future autonomous cars. Researchers propose different modes of organizing this kind of collaboration, from direct teleoperation of robots by one person, to crowdsourced interaction planning (Breazeal et al., 2013) similar to some of the management practices used in Mechanical Turk (see Irani and Silberman 2013; Ekbia and Nardi 2014) and programs such as Foldit (Cooper et al., 2010), to robots that support different modes of control from full teleoperation to multiple forms of shared control and full autonomy, such as NASA's upper torso humanoid Robonaut (Diftler et al., 2003).

In this fashion, robotics in the US has now explicitly moved from a rhetoric of full automation to a rhetoric of human-robot systems. Since there are few existing real-world applications of these systems, the design space is open. We, therefore, propose that now is a good time to intervene in this design space by attempting to rejig the rhetoric and concepts that have made invisible the labor relations underlying technical arrangements in robotics. Such invisibilization "deletes," in the sense Leigh Star used the term, the conditions of human labor that produce technological function (Star and Strauss, 1999; see also Engeström, 1999).

The concept of "labor" as it is used in this paper is roughly based on Marx's theory of labor and his notion of surplus value — i.e., under capitalism, human labor can be used to extract economic value for corporate owners at the expense of subsistence living for the laborer. We recognize that "labor" can and must have varied meanings, but we scope its use here for purposes of our argument. We argue that human-robot interaction should be seen as a labor relation in a political economy, not merely as a practical technical set-up or a simple human-machine partnership. One source of this labor in robotics is provided by the faculty, researchers, and students who build robotic systems, but are invisible in demonstrations of autonomously functioning robots (Suchman, 2007). Another increasingly important source of labor is users of social robotic technologies who become involved not only in physical labor that enables robots to function correctly in different environments (Forlizzi & DiSalvo, 2007), but also in the social and emotional labor required to construct robots as social agents. Social robots actively request that people treat them in a social manner through the use of anthropomorphic and zoomorphic forms and naturalistic social cues (Turkle, 2011). This design effectively hides the labor extracted from users by naturalizing it as caretaking, and subsuming it under the guise of a social relationship between the robot and the user. By shifting the discourse to labor relations, we open up the potential for discussions of the kinds of effects such relations will have at a larger societal level. We foreground the human labor that goes into making technical systems work, and we encourage analysis of issues such as the value of the labor needed in human-robot systems, equitable ways to manage that labor, and the kinds of returns on labor such arrangements entail both for laborers and owners.

To consider these issues, we use the concept of heteromation. Heteromation theorizes a class of computational systems that push critical tasks to end users as indispensable mediators (Ekbia and Nardi, 2014). In heteromation, system function relies on a heterogeneous set of actors. This human-machine division of labor contrasts to automation in which autonomous machines (largely) manage themselves and their jobs in much the way Dick's autofac machinery did (if not quite so independently). Automated systems are familiar to us all, and have profoundly changed manufacturing, data processing, financial services, and other arenas of work (see Figure 1). Heteromated systems, on the other hand, are less visible, and include newer systems we are just beginning to study such as microwork platforms, video games (in which players write documentation, train other players, provide valuable software modifications to extend games, and adjudicate disputes), personal health records, social media, review-based applications such as Yelp, and applications constructing the quantified self (at least those that supply data to corporations) (Ekbia and Nardi, 2014).



automation *heteromation*

Figure 1. The shifting image of work

Social media, for example, provide value to corporations through the labor of users who populate the databases of sites such as Twitter and LinkedIn, supplying personal information that can be resold to other corporations or used to drive advertising (van Dijk, 2009). Heteromated systems operate by quantifying, commodifying, dematerializing, and reducing people to a set of skills, attributes, and/or preferences. Through this process of algorithmic reduction, the labor of millions of people — some of it free, some of it very low cost—is efficiently extracted and managed. Phenomenologically, labor disappears into a reward system that often hides the fact that work is even being done (in, for instance, video gaming and social media), and constructs a compelling but sparse reward structure to stimulate participation. The benefits to corporations of free or low cost labor extend to savings in managing, scheduling, training, and disciplining workers who perform these functions themselves through algorithmic methods of control and peer help. Sometimes peer help and algorithms combine, as in the video game League of Legends' Tribunal. The Tribunal is a heteromated system of discipline in which players report and make judgments about miscreant players that are then processed by an algorithm that decides the correct punishment (Kou and Nardi, 2014). Unlike Dick's machines, which autonomously began rebuilding their ruined workplaces, heteromated technology inescapably relies on active human labor to produce outcomes.

2 Heteromated Robotics

One of the central questions about heteromation is: "Why does it work?" How do heteromated systems incite participation? What reward structures motivate participation such that corporations and organizations can extract value from labor? Heteromated labor affords a variety of satisfactions such as micro-validation (likes, follows, endorsements in social media), cognitive stimulation (games), enhanced physical capacity (quantified systems such as Fitbit), and even altruism (Diniz et al. 2013). In some cases, workers do the work simply because they feel they must as part of their jobs, or because they feel compelled by social norms or habituated social cues. This situation appears to characterize at least some robotic applications as we will discuss below.

How is human participation to be elicited in robotics, which has embraced a notion of human-robot systems? One key way is the agent-like and social appearance of robots as part of a design rationale which is trying to make computation more acceptable and workable to people who are not technical experts: the children, older adults, caretakers, and homemakers who will be using robots in their everyday environments. The new types of robots, particularly social robots, are designed so that people interact with them in ways that are as close to interacting with other people (or animals) as possible, and support their functioning through that interaction. One field of robotics which is moving in this direction is learning by demonstration, which develops robots so that people can teach them new skills by enacting those skills themselves—either showing a robot how something is done, or guiding the robot physically through the action (e.g., moving its hand to grasp a particular object and put it away) (see Argall et al., 2009).

The success of Mechanical Turk has shown that there is considerable labor to be had for the asking (Jiang et al. 2014). Aging populations, those caring for children or elders, and even children in the US, Japan, and Europe hold considerable potential for the work of training robots (e.g., Lockerd & Breazeal, 2004), which can be compensated with the low wages characteristic of Mechanical Turk or even simply the gratifications of cognitive stimulation and altruistic impulses. Rethink Robotics' Baxter, for example, is designed to be trainable for doing different factory tasks by line workers using manual demonstration, and would therefore be the kind of robot that would take advantage of such conditions. The social appearance of robots already engages people in heteromation, supporting the robots' functionality in ways that have been documented by researchers. Breazeal's Kismet deliberately uses an infant-like appearance and interactive cues to get people to patiently interact with the robot in ways that fit its AI capabilities (Breazeal, 2002). Infant-likeness is often used in robotics to diminish user expectations and increase their willingness to take time to teach robots new things. Social interactivity can serve a similar purpose; Sherry Turkle (2011) suggests that using social cues to entice people to nurture robots and support their functioning will be the "killer app" for robotics and the mode of its spread into our daily lives.

Research on the social mechanisms of successful human-robot interaction has shown that robots are not as autonomous as we popularly represent them to be. Their successful functioning inevitably involves significant efforts on the part of surrounding humans, whether they are researchers and doctoral students, nurses, elderly nursing home residents, or toddlers. Alač's (2011) observational studies of human-robot interactions between children, teachers, researchers, and robots in a nursery school showed that the social agency of robots is constructed not through their technical capabilities alone, but through the social orientations and actions of the people around them. Vertesi's (2012) ethnographic studies of NASA's Mars Rover missions show the robot's functions were supported through collaborative forms of social organization in the science team and participants' embodied enaction of robots' activities. Suchman (2007) points out that the social capabilities of Breazeal's robot Kismet, mentioned above, are "created out of sociomaterial arrangements that instantiate histories of labor." Studies of the robot vacuum cleaner Roomba in homes reveal that though the robot is sold as being autonomous, people need to do significant work to set up the environment so the Roomba can do its job well (Forlizzi & DiSalvo, 2007). With the Roomba and similar devices such as the Neato, it is necessary to remove certain furniture and articles from the floor, place barriers where the device might get stuck under a shelf or other piece of furniture, and be prepared to come to the rescue in areas of the home that just seem to confuse the robot.

So these commercial applications of robots, as few as they currently are, are already producing heteromation in ways made invisible by the notion of "autonomy" that continues to accompany robotic products, carrying forward the captivating vision of autonomous machines that awed Dick's character O'Neill. The labor that Roomba and Rover extract from participants shows how sociotechnical systems can make certain kinds of labor invisible and unacknowledged despite the critical role of such labor for system functioning. The infusion of more delicate human relations with robots, however, brings up important questions, as we see in the case of PARO.

2.1 The case of PARO: From autonomy to heteromation

Studies of the seal-like robot PARO have similarly shown that the robot's therapeutic success is not a function of the robot's technical design alone, but also of the supportive actions of people around it to contextualize it in ways that construct it as beneficial for adults in eldercare environments. PARO is a social robot designed in the form of a baby seal (See Figure 2). Covered with white plush fur, PARO's soft surface is layered over a set of sensors and microphones that enable it to sense touch, sound, and changes in position such as hugging (Chang et al. 2013). PARO is designed for patients with dementia, and several studies have demonstrated its ability to improve patients' moods, decrease stress, and increase interactions with others (Shibata, 2012; Chang et al., 2013).

In academic literature and robotic demonstrations, PARO is generally described as "autonomous." PARO's inventor Takanori Shibata says that the robot:

> acts autonomously…while receiving stimulation from the environment, as with living organisms. Actions that manifest themselves during interactions with people can be interpreted as though PARO has a heart and feelings. (2012)

In other words, people and PARO share a direct link—so direct that we might imagine that PARO has a heart and feelings with which to animate its interactions with humans, In fact, some older adults who interact with PARO describe it as having feelings and motivations (Kidd, Taggart & Turkle, 2006).

Figure 2. PARO—the robot seal

At the same time, Shibata describes PARO as an underdetermined and interpretively flexible socially interactive artifact, as in this statement from a talk for the Japan Society in New York:

> PARO has a limited number of functions as a machine. But through the interaction with human beings I designed PARO to evoke associations in the human's mind. So in that case it is not necessary for PARO to have all the functions, but the interaction can enlarge the number of functions. (2007)

This second way of describing PARO's interactivity suggests that, despite being technically autonomous, people's orientations and behaviors toward the robot have a significant role in bringing forth the desired therapeutic and social effects.

The first statement regarding PARO's autonomy suggests that an appropriate way to study PARO would be to see what kinds of effects its functionality produces. This approach is, in fact, what has been followed in most research. Studies measure various health outcomes following interaction with PARO (see Chang et al., 2014 for a review). The second definition of PARO as a more interactively situated artifact suggests the need for a broader framing for study and evaluation. Empirical studies of PARO's use outside of the laboratory, situated within a broader behavioral scope, paint a more nuanced picture of deployments of PARO and the human labor they involve (Chang et al., 2013; 2014). These studies focus not just on measuring aggregated outcomes such as stress levels, but on the mechanisms that produce the outcomes, as well as individual variation in responses to PARO.

Chang et al. (2014), for instance, reported the surprising finding that patients often ignored PARO, and did not become engaged until the social mediation of staff or other patients induced them to participate. Rather than connecting to the heart and feelings of the autonomous robot, these patients were uninterested until stimulated by other humans. Chang et al. summarize their observational study of PARO in a US nursing home, and point out ways it departs from other research on PARO:

> Our results indicate that interaction with PARO in the public is not as immediate and straightforward to establish as might be expected from prior studies, which rarely discuss the mechanisms by which interaction is started and maintained, or from videos of older adults interacting with PARO on the robot's website (http://www.parorobots.com/video.asp), which present only successful interactions. We rarely observed interactions between older adults and the robot spontaneously occurring in the field; more often interactors did not notice or were hesitant to interact with PARO (especially for the first time), or their attention was divided between the robot and other interests such as TV,

> puzzles, or observing other people. We also saw that most successful interactions of older residents with PARO occurred when staff and family initiated and encouraged them. (2014)

PARO thus appears to be a canonically heteromated system that needs human mediation to work effectively; it is an artifact in a heterogeneous sociotechnical system where the support of heteromated labor is essential for system function. Even the placement of the robot is crucial. Chang et al. (2014) noted that, unless placed by staff away from other things competing for patients' attention, the robot was not engaging to patients. Studies that reduce system function to a set of variables such as stress level, are likely to underspecify the actual functioning of digital technologies, thereby obviating knowledge of how these technologies work, and, crucially, how they might do some good if properly deployed. Systems such as One Laptop per Child have fallen prey to these very misunderstandings, squandering resources and leading to disappointment (Cervantes et al. 2011).

Like all artifacts, robots must be constructed and reinforced through social interactions (Restivo 2003). In acknowledgement of the importance of human labor to the functioning of PARO, Shibata's long-term collaborator Kazuyoshi Wada (2010) has started developing guidelines for how best to introduce and use PARO with older adults in institutional settings by observing and interviewing therapists who use the robot. Shibata himself has participated in the development of training and certification programs for caregivers that inscribe some of the ways in which people can support the robot's functioning (see http://www.parorobots.com/). This continuing work with PARO gives broader recognition to the notion that robotic systems, their functions, and consequences need to be developed, implemented, and studied as part of a broader social context. This line of work is also potentially creating a new form of expertise — the knowledge and ability to effectively implement assistive robotic technologies in human environments. It points to the emergence of novel, and often invisible, forms of the division of labor between humans and machines.

3 Discussion

The idea of "autonomy" as a generative metaphor has shaped a great deal of thinking and research in AI and beyond. A persistent trend, which can be called "Autonomist AI," has survived paradigmatic changes in approach and technique (Ekbia 2014). This trend is perhaps most explicitly represented in the research conducted on "autonomous agents." The standard definitions of these agents describe them as follows:

> Autonomous agents are computational systems that inhabit some complex dynamic environment, sense and act autonomously in this environment, and by doing so realize a set of goals or tasks for which they are designed. (Maes 1995)

> An *autonomous agent* is a system situated within and 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. (Franklin and Graesser 1996)

Although somewhat different in details, the common premise in both of these (and other definitions) is that they conceptualize autonomous agents *as inhabiting an environment*. However, as Wilson (2010) points out, "AI researchers have perhaps been more attentive, philosophically, to the autonomy that emerges for this agent ("its own agenda") than in how this autonomy has been and continues to be constituted through relations to a milieu ("within and part of an environment"). Thus, the work of humans to fill gaps in robots' abilities has historically been unacknowledged in influential formulations that ignore or downplay crucial aspects of an environment. Pragmatically, human-robot interaction is embraced in the rhetoric of social robotics, but is in conflict with the powerful trope of autonomy that renders human labor invisible.

The notion of mixed autonomy is subtly but critically different than heteromation. Mixed autonomy indicates that an autonomous agent undertakes certain tasks on its own, while turning to humans for other, known tasks (such as identifying an image). In heteromation, the system is not ever actually autonomous, but always requires human mediation. A Roomba left completely to its own devices will not clean the house. Nor will PARO improve health outcomes unless embedded within the scaffolding of a sociotechnical system that utilizes heteromated labor.

To the extent that "environment" is featured in accounts of autonomous agents, it acquires a very narrow and often underdetermined character. That is, environment is understood as a set of features and properties that the agent *senses* and *acts upon* (such as the Roomba figuring out it has reached the edge of a stair landing over which it should not plunge). What is often lost in this conceptualization is the fact that the environment also *supports* the agent in carrying out its actions. This is a basic but important insight, the flouting of which has serious implications for how we think about the world, about the nature of intelligence (natural or artificial), and about how we design systems. Heteromated labor is a key means by which the human "environment" supports robots in successfully completing their tasks, and should be theorized more openly in robotic design.

The ubiquitous portrayal of the humanoid robot in the media as a solitary and autonomous agent erases the surrounding support structure provided by human beings, devices, and infrastructures (see Figure 3). The issue, however, is deeper than simple media representation, and cuts into some of the fundamental aspects of the capitalist economy. Developments in the area of robotics illustrate this rather vividly, following the same pattern that was previously observed in other areas of computing technology (see Ekbia and Nardi 2014). The pattern looks roughly like this:

i. A new innovation is introduced, with the promise of automating some activity, reducing human burden;
ii. Technical limitations do not allow the full realization of the promise;
iii. Human beings are brought into the fold as users, customers, participants, or cheap laborers to compensate for the technical shortcomings;
iv. The contribution of human beings is unacknowledged and unrewarded.

(a) (b)

Figure 3. A robot with and without its support structure

One fear could be that something similar will happen with robots, where the work of the people who are left to support the robots in homes, eldercare institutions, and schools remains invisible when the workers are in fact doing significant labor to make the machines function. Remedies offered in dealing with this fear normally fall into one of two categories: (1) constrain the use of the technologies to only those areas where humans cannot or are not willing to participate—e.g., lifting and moving patients who are physically immobile (Turkle 2010), or (2) create a mechanism of micro-payments to compensate human beings for their labor (Lanier 2013). While providing minor improvements over the status quo, these suggestions only scratch the surface of deeper issues concerning how we envisage the relationship between humans and technologies, in a way doing disservice to both. There is no reason why we should limit technologies' use due to a nostalgic fantasy of a past bygone when people had the time and opportunity to take care of their children and elderly, to socialize with others at their whim, to write personal letters, to go on picnics, and so forth. The idea of micro-payments or other credit systems, on the other hand, takes the status quo as its point of departure, and accepts the rules of the game as they are currently dictated by corporate imperatives. These rules are not set in stone, nor are they actually that old; rather, they are the outcome of a set of neoliberal policies and practices that have been adopted and implemented in the last thirty years in the US, UK, and increasingly in other parts of the world (Harvey 2007). A major outcome of these policies has been the privatization of social services and infrastructures—from education and communication to pensions, prisons, and transportation—that had hitherto been wholly or partly provided by the public sector. Heteromated labor that drives technological systems has economic value in these privatized operations. The owners of the nursing homes and other institutions where robots might be deployed extract profit from patients' labor. The inventor of PARO details the commercialization of PARO (Shibata 2012), presumably an economic incentive for him.

The commodification of most aspects of contemporary life has turned technologies such as robotics into tools for profit-making instead of means of human well-being and social welfare. The push behind this trend is so strong that even the most perceptive observers take it for granted, and forget that one of the early promises of robotics and computer technologies in general was to reduce, not to add to, the burden of difficult labor for human beings, to provide more time for cultural activities and for taking care of oneself and of each other, and to facilitate and encourage participation in social affairs and political processes—very little of which has materialized according to mounting evidence (Sennett 2010). To reverse this process of commodification, policies and practices have to be in place that would encourage the integration of technologies in daily life not just as means for profit making but for making human life less burdensome, more humane, and more pleasurable. Domestic labor and caregiving to children and the elderly, for instance, can be considered as a form of social service, as it is in capitalist countries such as France. Under French law known as *Le droit à rémunération et les droits sociaux* members of a household can be compensated for such work (French Gov. 2014; see also *Ministère du Travail* 2014).

An important way in which human labor goes unacknowledged is manifest in research methodologies that do not conceive of technology as operating within a sociotechnical system (Kling 1996), and therefore do not generate holistic analyses that examine collective behavior and do not model environments more expansively. Positivist approaches in which variables are correlated and numbers crunched cannot discover how patients actually encounter a robot like PARO, or how humans in the environment contribute to robotic function. Chang et al. deepened our understanding of how robots can help patients through the realism of observations such as the following:

> The therapist in our study adopted multiple methods of generating interaction in the group, including asking questions, showing the interaction with PARO, and directing participants' attention to others interacting with PARO, switching between different mediation methods based on the personal needs of each participant and the group dynamics. (2013)

Our social robotics future could unfold in several ways. Perhaps it will be deemed sufficient to supply compromised patients with robots such as PARO. In other areas, such as manufacturing, robots replace human labor with only a few technicians to attend to operational details (Brynjolfsson and McAfee 2011). If it seems heartless to suggest that we similarly take humans out of the loop in caring for patients with dementia (and other ailments), we might ask why we consider it "too expensive" to pay people to attend the most vulnerable in a society in which we set no upper bounds on what is appropriate for the wealthy. (Space tourism, for example, is on the horizon.) Social robotics is explicitly intended to produce cost savings (Shibata 2012). In another possible future, we might recognize that heteromation is essential in social robotics, and just expect that people will do the work—a likely scenario in a tight labor market such as the current market, where the economic value of robotic deployments will not be distributed very widely beyond privatized interests. Or, alternatively, we might recognize and compensate heteromated labor by raising wages, rewarding the skills needed to use social robots to produce beneficial health outcomes. We might rethink social priorities and conduct objective research concerning the actual benefits of social robots as well as the full range of their costs. In privatized settings, such full accountings are rare. Technologies are assessed according to how they affect profits, not through a broader range of variables modeling human well-being and considering the externalities (such as e-waste) that accrue to all uses of digital technology.

Brynjolfsson and McAfee (2011) argue that machines are undeniably replacing human jobs. While this strategy generates profits, it also generates societal problems. The social and psychological sequelae of unemployment loom large in Europe, the US, and Japan. Even in wealthy, stable countries with a strong safety net such as Germany, unemployment may lead to a downward spiral of increasingly insecure employment. Precarious job conditions have arisen in Germany, with increasing part-time work, fixed-term contracts, marginal employment, and temporary work (Körner et al., 2012). These conditions lead to pathologies such as depression, anxiety, and lower self-esteem (Gallie et al., 2003; McKee-Ryan et al., 2005; Wanberg, 2012). If heteromated labor is needed to make PARO work, this might be the time to design a sociotechnical system that recognizes the reality of that labor, and, at the same time, considers how workers might share in the economic benefits more fully than a scheme of micropayments, which, in the end, amount to very little. The alternative of attempting to deploy robots such as PARO without sufficient human mediation seems a losing strategy, but the drive to replace humans with technology is strong, as Brynjolfsson and McAfee demonstrate.

4 Conclusion

The complexities of the operation of today's "autonomous" technologies leave us a long way from Philip K. Dick's enterprising machines, toiling at their own projects in the darkness of their underground factories. Perhaps this is a good thing; we can shed some light on human-machine relations, and attempt to shape them to fulfill goals of human well-being. What commercial robotics at its current state of development allows for is the conscious development of these systems in ways that can both acknowledge and suitably compensate labor, as well as assess the best ways to care for burgeoning populations of the elderly and sick.

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